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Increased flushing of Tarawa Lagoon: The potential for improving public and lagoon ecosystem health outcomes

NIWA Client Report: HAM2011-004
January 2011

NIWA Project: NZA11201

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Doug Ramsay

Prepared for

Ministry of Foreign Affairs International Development Group

NIWA Client Report: Ham2011-004
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National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

Client Report Reviewer's Report

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- ☐ The report's title adequately describes the report's main subject and purpose.
- ☐ The Executive Summary accurately summarises the report's background, scope, methods, results, discussion and conclusions.
- ☐ The report's purpose, objectives and scope are explained clearly and the client's brief is included or summarised.
- ☐ All important methods are described in sufficient detail and justified (where appropriate).
- ☐ The data/findings are analysed and communicated adequately:
  - ☐ Graphics and tables are used effectively to support the text.
  - ☐ All graphs are clear.
  - ☐ Graphs have full but concise legends, they are interpreted correctly in the text, and the key findings/conclusions are explained clearly.
  - ☐ Tables have clear, full explanatory captions, are clear, and are discussed and interpreted correctly within the text.
  - ☐ All figures, graphs and tables are referenced in the text.
- ☐ Statistical methods are used where necessary, appropriate tests are applied, relevant statistics and graphics are provided, and the results of these tests are interpreted correctly.
- ☐ The discussion places the findings within the context of existing knowledge and the investigation's purpose/objectives, and refers to the key relevant literature, as far as practical.
- ☐ The report adequately addresses the project's objectives and the client's needs.
- ☐ The information within each section is arranged purposefully and logically, and the order of sections is logical.
- ☐ All assistance is acknowledged, including all contributors to the work and sources of funding and data.
- ☐ All literature cited in the text is fully referenced in the References section.
- ☐ The text is clear and concise, and the vocabulary and content are appropriate to the target readership. No irrelevant material is included. Spelling, grammar, punctuation and formatting are correct.
- ☐ The report meets NIWA's high science and professional standards.

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Contents

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Executive Summary

This report has been prepared for the International Development Group (IDG) of the New Zealand Ministry of Foreign Affairs. It follows a request from the New Zealand Minister of Foreign Affairs during a recent trip to Tarawa to to summarise what is known about the current state of pollution in Tarawa lagoon, the effect this has on both public and lagoon ecosystem health, and whether opening installing causeways or openings in existing causeways would improve flushing of the lagoon, and have a positive impact on both the considerable human and ecosystem health-related problems being experienced.

On South Tarawa there are a wide range of human and animal waste-related contamination sources and a wide number of contamination pathways. Virtually every sanitation system or practice currently in place in South Tarawa contributes to contamination of the groundwater and / or immediate coastal waters in some way.

Where the lagoon or ocean coastal waters forms part of the contamination pathway, there are two main mechanisms that can result in human-related public health issues: 1) contact with contaminated seawater, and 2) consumption of contaminated shellfish. Faecal contamination of both lagoon water close to the shoreline, and shellfish flesh have in general (and excessively so) exceed safe levels for some considerable time. Whilst there is no information on the relative influences of the various contamination pathways resulting in human health issues, both of these are likely to be significant given the number of I-Kiribati who bathe or swim in the lagoon each day, and the amount of shellfish that are collected for consumption.

Past assessments of nutrient levels in the lagoon had concluded that the high level of tidal flushing and uptake by the benthic biota in South Tarawa was sufficient to assimilate the levels of natural and waste-related nutrients entering the lagoon. However, the algal bloom that occurred in December 2009/January 2010 does indicate that this situation is rapidly changing and that that nutrient loads entering the lagoon now (or under certain circumstances) exceed what can be effectively dispersed by lagoon flushing or taken up by the marine benthic biota in the southern part of the lagoon. If left unchecked and nutrients accumulate in sufficient concentrations for such algal blooms to continue or become more frequent, significant ecological damage will occur.

Flushing in Tarawa lagoon is dominated by the tide and the exchange of water over the western boundary. Whilst currents over, and in the vicinity of, the sand flats and southern part of the lagoon are low, over a tidal cycle a high level of flushing does occur due to the high tide range and twice daily exchange of water between the sand flats and the southern part of the lagoon.

In contrast very little water exchange, relative to tidal flushing, occurs through any of the open channels in South Tarawa or would have occurred through any of the original causeway openings.

Despite the high tidal flushing overall that occurs each day over the lagoon sand flats, pathogenic faecal organisms become a human health risk as soon as they reach the water. Hence flushing and dilution, to a low enough level to reduce health risks, would need to be near-instantaneous over the sand flats to reduce public health risks from contaminated lagoon water of South Tarawa. Given the contamination loads that are picked up by the rising tide each day and the distributed nature along the shoreline of this load, the small increases in flushing over the sand flats that would be achieved through opening up any or all of the causeways would not reduce contact or shellfish-related health risk over the sand flats and would not make any discernable difference to public health outcomes.

In terms of nutrient concentrations, causeways construction will have been a factor in the lagoon ecosystem health issues now beginning to be seen (albeit a minor one relative to the source issues). Increasing the flushing potential and reducing residence time, particularly in the south-east corner of the lagoon may have some limited positive benefits to the lagoon ecosystem in the short term. However, if the magnitude of the nutrient loads entering the lagoon are not significantly reduced, opening up some or all of the causeways will do nothing to stop significant lagoon ecosystem damage in the foreseeable future.

Whilst improving flushing potential in the south-east corner every little will help, it is unlikely that the cost of doing so would justify the small improvements that could be achieved. Only increasing the flow through the Tanea-Buota channel and opening up part of the Bonriki to Tanaea causeway, are the costs likely to be low enough to consider.

Creating openings in the causeways along the central to western part of South Tarawa (between Taborio and Ambo, Taeoraereke to Nanakai to Bairki, and also at Temaiku) will result in limited exchange of water and flushing of either nutrient rich lagoon water reaching the ocean, or ‘clean water from the ocean reaching the lagoon. Openings in any of these causeways will have the potential of causing significant shoreline changes.

In improving lagoon ecosystem health, as with public health outcomes, addressing the sources of contamination, through effective water and sanitation provision and behavioural change, is the only way any substantive improvement can be made. Such improvements will not be achieved through increased flushing. Not only would this reduce the contamination pathways via the lagoon, but also address most of the other potential pathways as well. The approach planned for the Betio and Bairiki Peri-Urban Slum Upgrading and first phase of the subdivision at Temaiku under the Sustainable Towns project would appear to provide an effective approach. However, care needs to be taken to ensure the effluent disposal via the existing and any new ocean outfalls are properly assessed and constructed to prevent potential human-health and reef ecology impacts being moved to the ocean side coast.

1. Introduction

1.1 Background to this report

This report has been prepared for the International Development Group (IDG) of the New Zealand Ministry of Foreign Affairs. It follows a request from the New Zealand Minister of Foreign Affairs during a recent trip to Tarawa to have options assessed for improving lagoon water quality, specifically the impact of installing culverts or openings in existing causeways to improve flushing potential of the lagoon.

The report builds on discussions held during the Lagoon Restoration Roundtable held in March 2010 at the Teuanete Conference Room, Tebunia, South Tarawa. The two South Tarawa Urban Councils (Betio and Teinainano) recognise the importance that the condition of the lagoon has on the socio-economic well-being of their communities. Teinainano Urban Council's (TUC) strategic plan has made the restoration of the Tarawa lagoon its highest priority with this objective also supported by Betio Town Council (BTC).

A visit to Tarawa was conducted between the 4-11 November 2010. The terms of reference for the visit are contained in Appendix 1. Discussions were held with a range of stakeholders (summarised in Appendix 2) and an assessment of each causeway was conducted at both low and high spring tide over the 6-7 November 2010.

1.2 Outline of this report

The next section, Chapter 2, provides and overview of the public and ecosystem implications of pollution in Tarawa lagoon, discusses the pollution sources and water-related contamination pathways and summarises what is known about pollution levels in the lagoon.

Chapter 3 provides a summary of past studies that have investigated the influence of the various channels on lagoon flushing and pollution levels and provides a discussion of the potential opportunity, impact and issues related to opening up each channel.

Chapter 4 provides a brief discussion on relevant ongoing or planned development initiatives in South Tarawa, focussing on potential opportunities and issues related to public and lagoon ecosystem health. A summary of the recommendation and conclusions from the study are provided.

2. Current state of Tarawa Lagoon

2.1 Public and ecosystem health implications of pollution in Tarawa Lagoon

Contamination of the southern part of Tarawa lagoon due to human and animal excreta has been a major problem since at least the 1970s. This results in two primary impacts:

- A public health impact due to the potential range of pathogenic (disease-causing) micro-organisms[1] that are found in faecal wastes (e.g., from humans, pigs or birds). Table 1 lists some of the common water-borne pathogens and their human-health impacts (unfortunately routine microbiological testing is not conducted at the hospital to determine the organisms responsible for particular pathogenic public health outbreaks).

- A lagoon ecosystem impact due to high nutrient accumulation which leads to disruption of the normal way the lagoon ecosystem functions.

Kiribati has one of the highest incident rates of diarrhoeal diseases in the Pacific with 766 and 634 cases per 1000 population in 2008 and 2009 respectively. In 2009, 62,723 diarrhoeal diseases required inpatient care with 11,594 of cases occurring in children under 5 years resulting in 9 deaths (WHO, 2010). Typhoid outbreaks have also occurred in both 2009 and 2010. Previous assessments have indicated that a high proportion of the total diarrhoeal disease incidence in Kiribati occurs in South Tarawa, particularly in Betio. The vast majority of these cases are considered to be directly attributable to unsafe drinking water, inadequate sanitation and poor hygiene.

These incident rates have increased substantially over the last few years and have also seen an increase in other pathogenic-related symptoms such as cold and flu symptoms; skin, eye and ear problems and, in particular, an increase in festering of cuts and sores after immersion in lagoon water.

Water quality testing was conducted from 30 samples taken from the reticulated water system, groundwater wells and rainfall catchment systems on South Tarawa by the US Navy as part of the US Pacific Partnership in August 2009. This found that 60% of the samples tested positive for faecal coliforms, and 65% of wells had nitrate levels above safe levels, most excessively so. High nitrate levels in drinking water consumed during pregnancy are thought to contribute to babies with an increased risk of birth defects. It can also lead to methomoglobinemia (Blue-baby syndrome) in infants who

[1] In this report these are assumed to be bacteria, protozoa, viruses and helminths (worms).

are fed water or baby formula made with water high in nitrates, and potentially via mother's breast milk where the mother consumes water high in nitrates. If untreated this can be fatal. Boiling water that is high in nitrates increases the nitrate concentration and the potential risk.

Table 1: Common waterborne pathogens (Ministry of Health, 2007)

Disease	Micro-organism	Common source	Symptoms
Bacteria			
Verotoxic E. coli	*Escherichia coli* O157:H7	Intestines of animals and infected people	Cramping, vomiting, diarrhoea (occasionally bloody), fever, dehydration. Can develop into haemolytic urenemia syndrome
Salmonellosis	*Salmonella typhimurium*	Animals and birds	Abdominal pain, diarrhoea, chills, fever, vomiting and nausea
Typhoid fever	*Salmonella typhi*	Faeces of human typhoid carrier or case	Fever, usually rose spots on the trunk, diarrhoeal disturbances
Paratyphoid fever	*Salmonella paratyphi* (ABC)	Faeces of human carrier or case	Fever, diarrhoeal disturbances, sometimes rose spots on trunk, other symptoms
Shigellosis (bacillary dysentery)	*Shigella*	Faeces of human carrier and infected people	Sudden onset diarrhoea, constant urge to defecate, fever, frequent stools containing blood and mucus
Campylobacter enteritis	*Campylobacter jejuni*	Chickens, swine, dogs, cats, humans, raw milk	Watery diarrhoea, abdominal pain, fever, chills, nausea, vomiting, blood in stools
Cholera	*Vibrio cholerae, Vibrio comma*	Human faeces, vomit; human carriers, shellfish	Diarrhoea, rice-water stools, vomiting, thirst, pain, coma
Protozoa			
Amoebiasis (amoebic dysentery)	*Entamoeba histolytica*	Bowel discharges of carrier and infected people; possibly also rats	Diarrhoea or constipation, or neither; loss of appetite, abdominal discomfort; blood, mucus in stool
Cryptosporidiosis	*Cryptosporidium parvum*	Farm animals, human, fowl, cats, dogs, mice	Mild flu-like symptoms, diarrhoea, vomiting, nausea, stomach pain
Giardiasis	*Giardia lamblia*	Bowel discharges of carrier and infected people; dog, possum	Prolonged diarrhoea, abdominal cramps, severe weight loss, fatigue, nausea, flatulence; fever is unusual
Viruses			
Viral gastroenteritis	Rotaviruses, *Norovirus*	Human faeces, or sewage	Nausea, vomiting, diarrhoea, abdominal pain, low fever
Infectious hepatitis	Hepatitis A	Faeces from infected people	Fever, nausea, loss of appetite; possibly vomiting, fatigue, headache, jaundice

In December 2009 and January 2010 there was anecdotal evidence of a phytoplankton bloom affecting the southern part of Tarawa lagoon, Figure 1 (Webb, 2010). Where increased levels of nutrients (such as nitrates, phosphorous and potassium) are input in to a system such as Tarawa lagoon, this stimulates biological productivity at the lowest points in the lagoon food chain such as phytoplankton and zooplankton. Where this stimulates excessive reproduction of these organisms this can be seen visually in the form of a bloom. In tropical atoll lagoon systems such blooms are generally rare and previous studies (Johannes et.al., 1979; Kimmerer and Walsh, 1981; Naidu, 1991; Kimmerer, 1994) have all concluded that to date the flushing characteristics and capacity of the lagoon benthic biota in Tarawa lagoon has been sufficient to assimilate both naturally occurring oceanic, due to equatorial upwelling waters in the region, and human nutrient inputs.

Figure 1: Potential phytoplankton bloom along South Tarawa during December 2009-January 2010 (Photo: Dr Arthur Webb, SOPAC).

However, the occurrence of the recent bloom is an indication of excessive levels of nutrients entering the lagoon system. In a simple sense, the lagoon system is now becoming dangerously out balance between the amount of nutrients entering the lagoon, and how the lagoon can accommodate and deal these nutrients through: 1) dilution and dispersion due to flushing (the effectiveness of which will have been reduced due to the causeways), and 2) the assimilative capacity of the lagoon benthic biota in the southern part of Tarawa lagoon. On South Tarawa, the most significant increase in nutrient input to Tarawa lagoon is likely to be nitrate and phosphate produced from the breakdown of human or animal waste, and is a typical by product of sanitation systems such as septic tanks and latrines.

The possible reason for the bloom initially occurring is potentially to be due to the high rainfall that occurred (Webb, 2010) during December and January (554.6 mm and 486.3 mm or approximately 3 and 2 times respectively the typical amount of rain that occurs during these months). This would have lead to an increased flow of groundwater (and also surface run-off) into the lagoon and hence increased input of water-borne contaminants and nutrients in to the lagoon.

If nutrient concentrations remain in high enough concentrations to enable excessive algal and plankton growth and such blooms to continue to develop and become more frequent this can lead to eutrophication. This can rapidly lead to disruption or changes in the normal functioning of the lagoon ecosystem leading to problems which include oxygen depletion, a loss of fish and shellfish and a reduction in biodiversity, and potential health problems, either directly through toxic algal blooms or indirectly for example ciguatera poisoning.

2.2 Pollution sources and contamination pathways

On South Tarawa there are a range of human and animal waste-related contamination sources and a wide number of contamination pathways that can lead to public or ecosystem health impacts.

The dominant source of contamination and resulting waterborne-related public and lagoon ecosystem health impacts is the lack of adequate residential sanitation infrastructure. Sanitation practices in South Tarawa, based on information from the 2005 census, are summarised in Figure 2. More recent information based on a survey of 420 households in Betio and Bairiki as part of the Sustainable Towns Project identified that only 37% of households have their own toilet with the remainder sharing a neighbours, using a communal toilet, or using the ocean or lagoon beach. Of those households using toilets, 24% use a flush system, 58% pour flush, and 3 % composting toilets. 15% are primarily reliant on lagoon or ocean beach (PIAC, 2010). Virtually every current sanitation system or practice currently in place in South Tarawa contributes to (pathogenic) contamination of groundwater and / or the immediate coastal waters in some way. A simplified overview of potential contamination pathways in relation to public health issues is shown in Figure 3.

In addition to contamination from human-related sources, the practice of keeping both dogs and pigs largely uncontrolled and close to each household, contributes further contaminant loading to surface water, groundwater and the lagoon.

Further pollution sources to lagoon and ocean coastal waters are also related to sewage disposal directly to these receiving environments, particularly:

- From shipping that is berthed at the wharf or anchored within the lagoon at Betio. At presentation there is no enforcement of regulation preventing such lagoon disposal but an inter-government water pollution committee has recently been formed to address the issues.

- On the ocean shoreline in the vicinity of some or all of the four ocean outfalls at Betio, Bairiki, Bikenibeu and Tungaru Hospital. The salt-water system was designed so that the sewage discharge, which is currently discharged at around 10 m below sea level off the edge of the reef, would be of similar or greater density than the receiving seawater. This resulted in the discharge tending to head down the frontal reef slope, away from the coast, and be diluted and dispersed in deeper water and is an effective approach to sewage disposal in atoll environments. However, with the breakdown of the saltwater flush system and the move to a dominantly pour flush system using less dense fresh/brackish groundwater, this results in the sewage discharge from the outfall tending to rise to the surface. Anecdotal information suggests this is occurring at least at the Betio and Bonriki outfalls with at least part of the resulting plume possibly coming back on shore over the fringing reef.

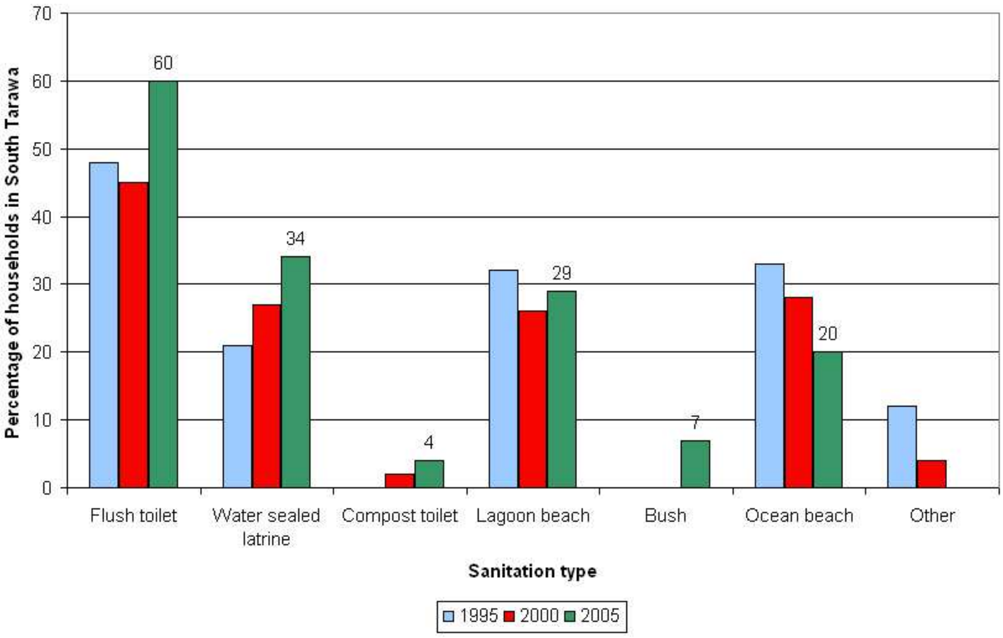

Figure 2: Changes in sanitation practices in South Tarawa between 1995 and 2005.

Drinking contaminated water and a lack of hygiene form major pathways for pathogenic-related public-health problems. In terms of groundwater-related contamination pathways, with the exception of high temperatures, most other factors that influence the inactivation of pathogenic bacteria and viruses favour their extended survival and sub-surface transport (Dillon, 1997). In particular the sandy nature of the soils on South Tarawa, and the high infiltration rates, means that there is limited capacity for organisms from either surface or subsurface sources of human or animal wastes to be filtered or absorbed, making it extremely difficult to protect groundwater on South Tarawa unless the source of the contamination is controlled.

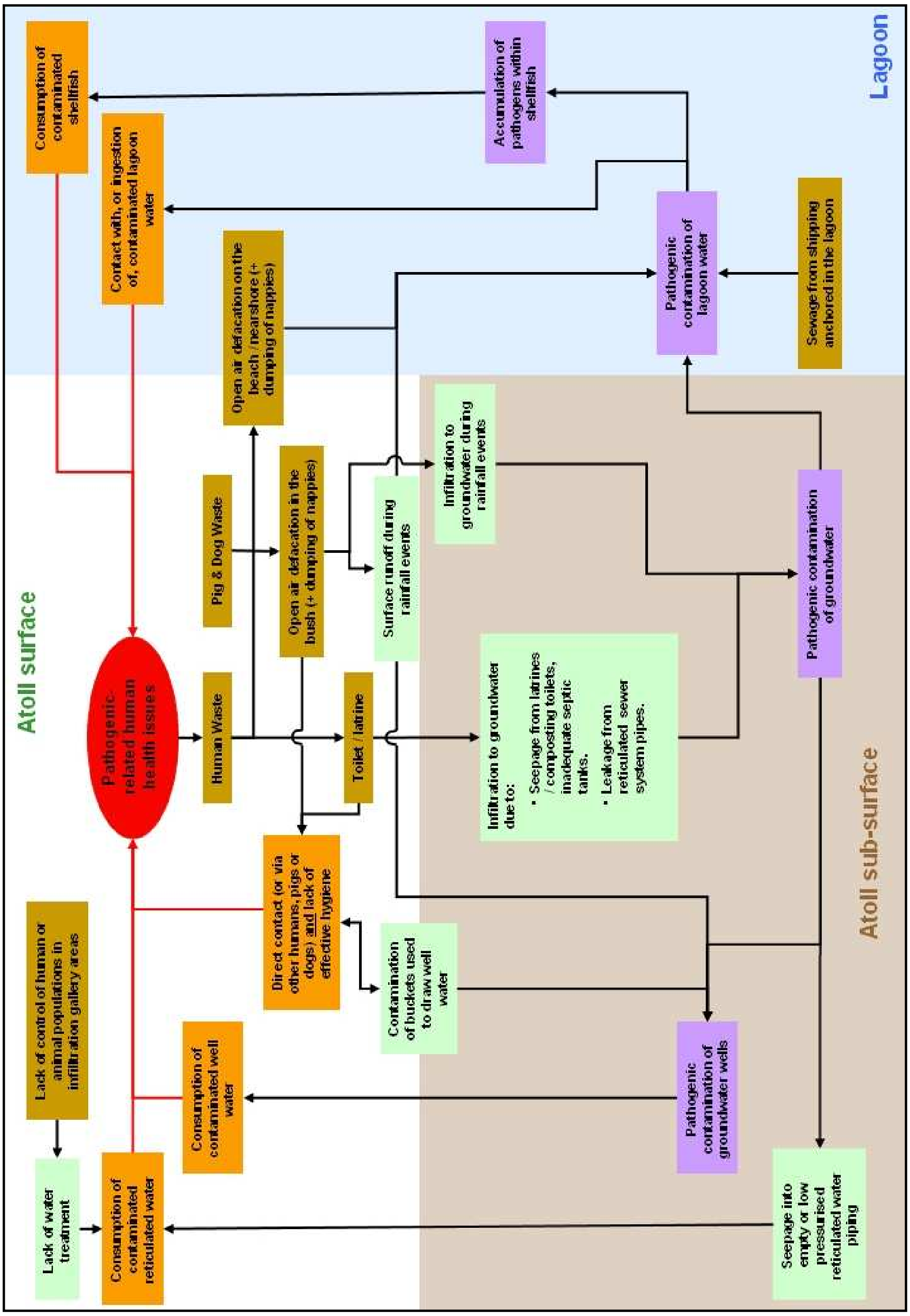

Figure 3: Simplified representation of the main public-health related pollution sources and waterborne pathways for pathogenic organisms (bacteria, protozoa, viruses, helminths).

Where the lagoon or ocean coastal waters forms part of the contamination pathway, there are generally two main mechanisms that can resulted in pathogen-related public health issues:

- Contact with contaminated seawater, for example during bathing: Pathogens can enter the body if water is swallowed, inhaled or come in to contact with ears, nasal passages, mucuous membranes or cuts in the skin (MfE, 2003). In the many cases the ill-health effects from exposure to contaminated water are minor and short-lived. However, there is the potential for more serious diseases, such as hepatitis A, giardiasis, cryptosporidiosis, campylobacteriosis and salmonellosis (MfE, 2003).

- Consumption of contaminated shellfish: Shellfish are filter feeders and can accumulated pathogenic micro-organisms, viruses, protozoa, marine biotoxins, heavy metals or other toxic substances within their tissues. The human-health risk is particularly high where shellfish are consumed raw, with some diseases causing viruses able to withstand both freezing and cooking. In many parts of the world the consumption of shellfish has been associated with outbreaks of viral gastroenteritis and hepatitis A infection caused by faecal contamination of coastal waters with human waste. The consumption of contaminated te bun (*Andara maculosa*) was a factor in the cholera outbreak in 1977/78

At present there is no information available on the relative influences of the different contamination pathways resulting in human health impacts.

In lagoon and coastal waters, faecal bacterial and viruses reduce with time due to inactivation or death. Salinity, temperature and turbidity all influence the rate of inactivation but it is exposure to solar radiation that has the most significant effect. In Kiribati, during daylight and in sunny conditions faecal bacterial are reduced by about 50% in 6 hours (Kelly, 1994). Viruses on the other hand can be present for many weeks after release in to the lagoon environment. Nutrients, in essence, remain in concentration until there are either diluted and dispersed by flushing or are taken up by lagoon biota. They become detrimental to the lagoon ecosystem if they remain in high enough concentrations that results in excessive algal and plankton growth.

2.3 Lagoon water quality

Limited information of coastal lagoon or ocean water quality is available. Ad hoc monitoring has been conducted, including in 1979 after the cholera outbreak in 1977/78 (Johannes et al., 1979), various University of the South Pacific activities, (Naidu et al., 1991; Kelly, 1994), and as part of the Tarawa Lagoon Restoration Project (Kimmerer, 1994; Danielson et al., 1994)[2].

Currently the Environmental Health and Laboratory Units under the Ministry of Health and Medical Services monitors the quality of well water, rain water, Public Utilities Board reticulated water, and lagoon and ocean water (Figure 4). According to the Unit, parameters that have been tested include Ph, conductivity, dissolved oxygen, salinity, turbidity, temperature nitrate/nitrite (but the equipment has been broken for some time), chlorine, lead, and faecal coliforms. Unfortunately the data is not available as the computer and back-up that held the data was stolen in 2010 and attempts are currently underway to recover the data from the original recording sheets where they have been kept. However, in the case of lagoon and ocean monitoring it is doubtful whether the results could be used to look at the long-term changes in water quality as samples tend to be collected on the same day (Tuesday) each month and depending on the tide are not collected at the same location (either close to the shoreline if the tide was high or out on the sand or reef flat if the tide was lower). As is discussed in the next section, contaminant concentrations can vary substantially depending on their location across the sand flat and on the state of the tide.

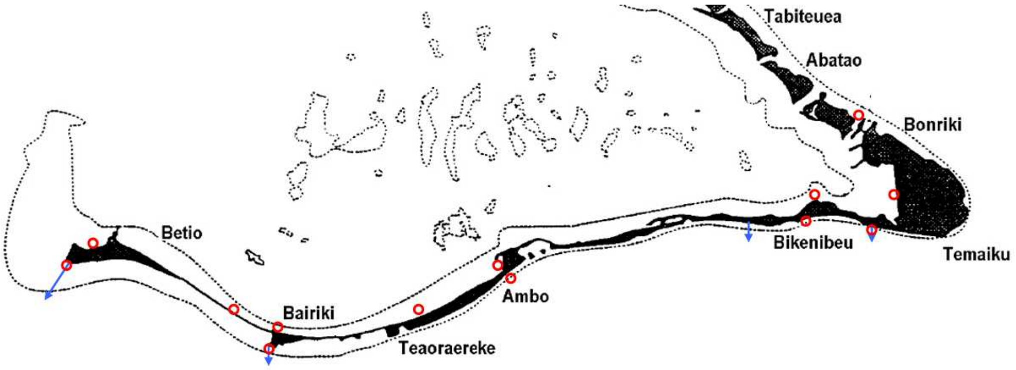

Figure 4: Location of Environmental Health Unit lagoon and ocean monitoring (red circles). The location of the four ocean outfalls are shown by the blue arrows

2.3.1 Lagoon bacterial contamination patterns

Figure 5 summarises the bacterial results from lagoon and ocean reef water samples presented in Johannes et al. (1979) and Naidu et al (1991). Kelly (1994) also found that mean faecal coliform counts exceeded 350 / 100 ml at 7 of 12 lagoon sites and 2

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[2] Both the Kelly and Danielson reports have not been able to be viewed as part of this assessment.

of 3 ocean outfall sites with the highest levels (>2,000 / 100 ml) occurring in the eastern corner of the lagoon.

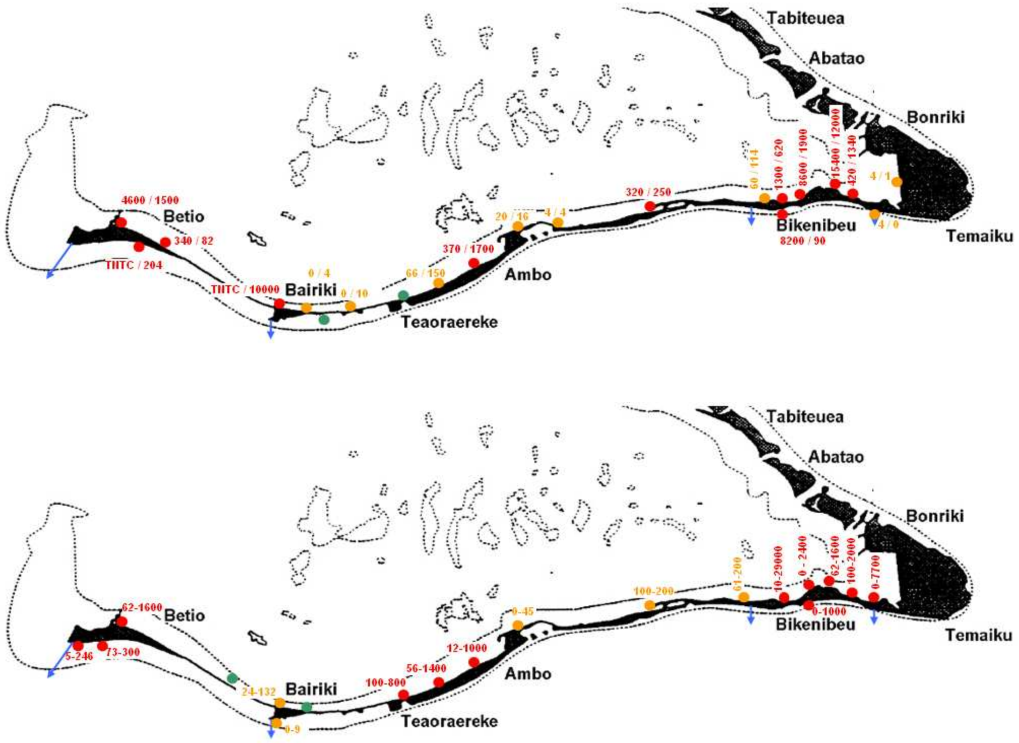

Figure 4: Bacterial results presented in Johannes et al.,(1979) (top) and Naidu et al.,(1991) (bottom). Red dots indicate bacterial counts above 200 / 100 ml, orange between 0 and 200 / 100 ml and green, no bacterial accounts. TNTC = Too numerous to count. Blue arrows show the location of the ocean outfalls. The values on the top plot show the bacterial counts for faecal coliform / faecal streptococci, with the values on the bottom plot the lowest and highest faecal coliform counts taken over three sample dates.

The conclusions drawn by all these studies indicate that bacterial contamination is predominantly from human sources with the highest levels occurring in the proximity of the areas with the highest population densities. It also suggested that:

- Highest contamination typically occurred during falling tides and in the morning. This is likely to be due to increased use of the lagoon as a toilet during the night / early morning and the high bacterial die-off during the day due to inactivation by exposure to solar radiation.

- Lower contamination levels towards edge of reef / sand flat and on the rising tide.

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Contamination decreased with tidal flushing, i.e. increased dilution and removal of nearshore contamination occurred on Spring tides compared to neap tides. However, prior to this flushing faecal concentration levels are very high for a couple of hours each day.

Whilst no monitoring data is available since 1994, the same pattern of contamination will be occurring, and indeed worsening, along south Tarawa as the population has continued to increase from around 28,350 in 1995 to unofficially around 50,000 in the 2010 census.

At both Bairiki (east of the harbour) and Betio (east of the port reclamation) during the visit in November there were pockets of visually polluted water and a foul odour. Johannes et al., (1979) noted this as a local issue at Bairiki also, with it being due to the structures / reclamation trapping and concentrating benthic algal detritus (albeit there was evidence of nappies and other human contamination sources also during the visit in November) due to the easterly wind-driven surface currents resulting in a localised stagnant area.

The above observations suggest that:

- In general Tarawa lagoon is very well flushed due to the high tide range and large volume of water that is exchanged over the open western boundary of the atoll (and between the sand flats are deeper lagoon). Indeed water quality in the lagoon would be much worse if water exchange over the western boundary was restricted by a reef flat and motu as on the east and southern coasts.

- It is the high input of human waste that is occurring on a daily basis that is then picked by the rising tide, particularly in the morning that is causing the high contaminant levels and the contamination gradient across (from shoreline to the lagoon edge) the sand flats along South Tarawa. This daily cycle is shown in a simplified form in Figure 5.

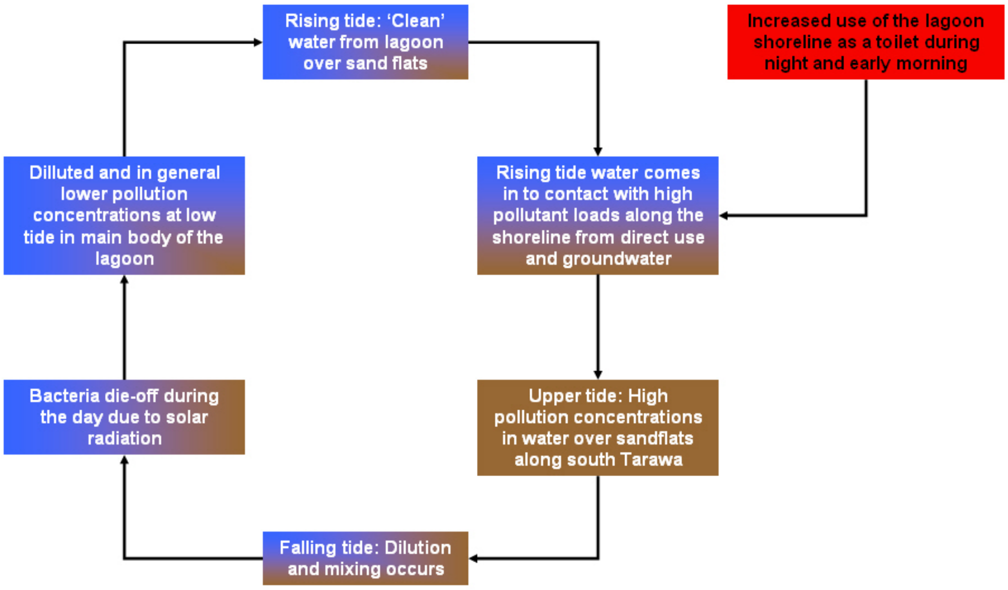

Figure 5: Simplified daily cycle of contaminant loading and subsequent dilution and bacterial die-off along South Tarawa.

2.3.2 Shellfish contamination

The previous studies of bacterial contamination in lagoon water summarised above also assessed bacterial contamination in commonly consumed filter-feeding bivalve molluscan shellfish. The cholera outbreak in 1977/78 was in part due to the consumption of contaminated shellfish (te bun, *Anadara maculosa*). No known information or studies have been found on potential levels of enteric viral contamination shellfish.

The patterns of bacterial contamination in shellfish recorded by Johannes et al., (1979) and Naidu et al, 1991) are summarised in Figure 6. Levels varied depending on species and location over the reef flat where they were gathered but in most cases vastly exceed safe consumption levels. Again contamination levels in the south-east corner off Bikenibeu were higher than further west. Kelly (1994) also found that faecal coliforms levels in edible shellfish at all sites monitored exceeded U.S. National Health standards at all sites.

Given the continued population increase and pollution issues since this time it is unlikely that there any shellfish gathering locations over the sand flats along South Tarawa that won't result in risk of severe health outcomes when consumed.

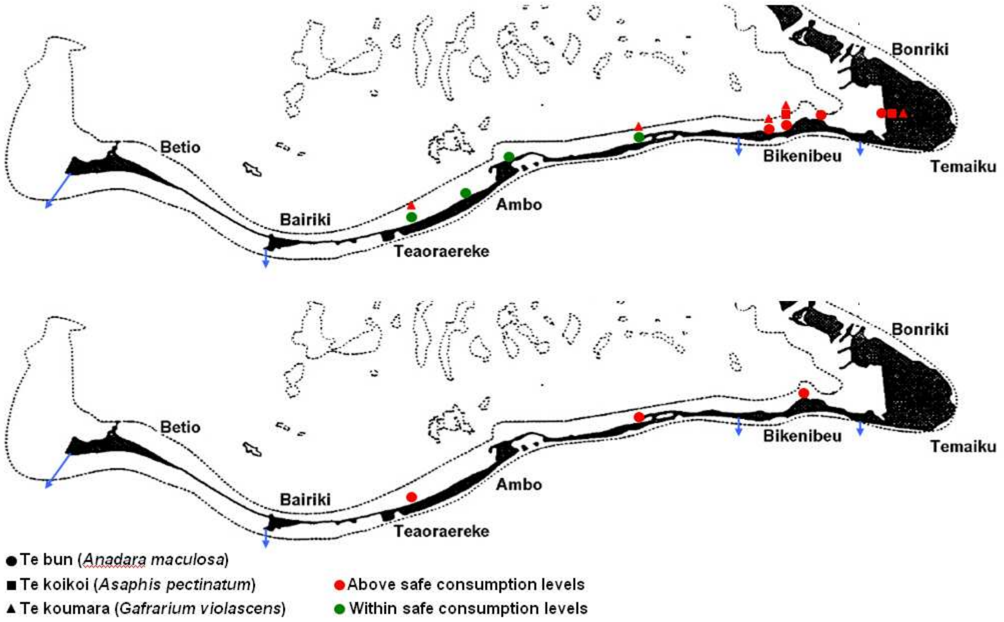

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Figure 6: Summary of shellfish faecal coliform levels in shellfish as reported by Johannes et al., (1979) (top) and Naidu et al, (1991) (bottom).

2.3.3 Nutrient levels

Water chemistry measurements were included in the studies by Johannes et al, (1979), Kimmerer (1981), Naidu (1991), Kelly (1994) and Kimmerer, (1994). All these studies concluded that the nutrient loading from human waste enter the lagoon was not at the time causing a detrimental impact on the lagoon ecosystem. However, as discussed in Section 2.1 this situation appears to have changed. Given the nutrient issue is due to increased concentrations, the most severely affected areas are again where the population is higher and flushing is lowest along the central and eastern parts of South Tarawa.

On the ocean side, Kaly (1996) carried out a detailed assessment of the effect of sewage release from the existing outfalls on the adjacent reef ecology prior to the rehabilitation of the sewage schemes in Betio, Bairiki and Bikenibeu under the ADB funded Sanitation, Public Health and Environment Improvement Project. This found a relatively high impact on the outer reef ecology related to the outfalls discharging in relatively shallow water but that this could be reduced in the saltwater system was functioning and the outfalls could be extended in to deeper water. Anecdotal evidence suggests that at present algal cover has largely deplaced coral cover over much of the areas surrounding the various outfalls, which is indicative of excessive nutrients.

3. The potential for improved lagoon flushing

3.1 Overview of past studies assessing the influence of channels on flushing

South Tarawa has approximately 5.1 km of causeways (Figure 7) that have closed naturally occurring channels between islets (Webb, 2010). The construction of these causeways and resulting blocking or reduction in the interchange of water between the lagoon and the ocean side is an exacerbating factor in the water quality issues being experienced in the southern part of Tarawa lagoon. The causeways are not the fundamental cause, for example water quality problems were occurring at Betio, long before the Dai Nippon causeway was constructed

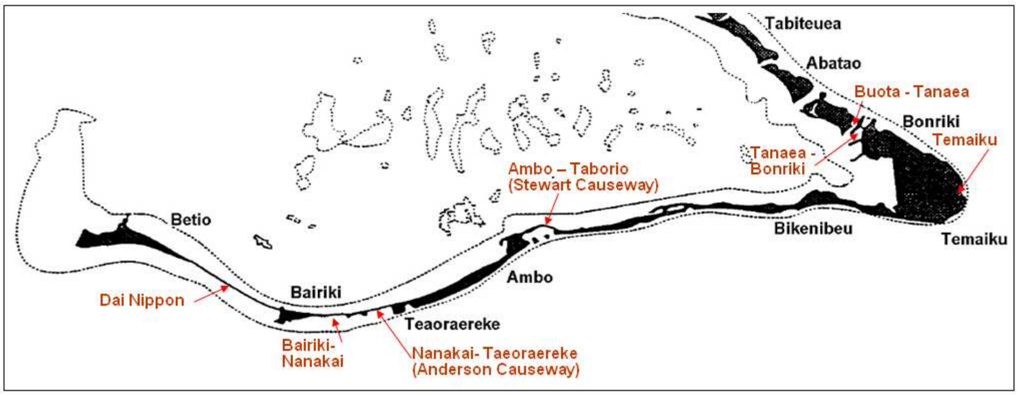

Figure 7: Causeway locations on South Tarawa

A number of past studies (Chen and Kimmerer, 2004; Royds Consulting Ltd, 1996; Damlamian and Webb, 2008) have assessed the influence of the channels in South Tarawa on water quality and circulation within Tarawa lagoon. Each of these studies have limitations, namely most assume complete removal of the causeway and an exchange of water over the complete removed length, but some generally conclusions can be drawn and are summarised below.

Most significantly these previous studies indicate that the exchange of water through the channels along both the eastern or southern coastlines is extremely small, relative to the average lagoon volume or the volume of water that is exchanged through the western boundary, Table 2. On the eastern channels, flow is predominantly (98% of the time, (Damlamian and Webb, 2008) from the ocean to the lagoon side due to wave set-up effects on the tradewind ocean shoreline unless strong winds occur from the west when a lagoon to ocean flow can occur around high tide. On the southern coast net flow tends to be from lagoon to the ocean but this depends primarily on wind conditions. However, the volume of water exchanged would be low due to the lack of any significant wave set-up on the ocean reef and minimal difference in tide level between lagoon and ocean, particularly along the western half of South Tarawa.

Table 2: Summary of water exchange measurements through various channels and openings in Tarawa lagoon.

Channel or opening	Exchange through channels and openings expressed as a percentage of mean lagoon volume[3]	Reference
Over the western boundary	44% and 46% of the mean lagoon volume during flood and ebb respectively on a Spring tide.	Damlamian and Webb, (2008)
12 eastern channels (total)	2.1% and 0.16% of mean lagoon volume over a Spring and Neap tide respectively (in to the lagoon)	Damlamian and Webb, (2008)
6 Eastern channels (total)	0.46% of mean lagoon volume over a high tide (in to the lagoon)	Chen et al (1994)
Tanaea to Buota	0.04% of mean lagoon volume over a high tide (in to the lagoon)	Chen et al (1994)
Tanea to Buota	0.03 of mean lagoon volume over a tidal cycle (in to the lagoon)	Groves and Yeeting (1981)
Bairiki to Betio	0.14% and 0.06% of mean lagoon volume over a Spring and Neap tide respectively (out of the lagoon over 3.25 km of reef flat)	Kimmerer and Walsh (1981)

Chen et al (1994) concluded that approximately 25% to 30% of water in the southeastern corner of Tarawa lagoon would have originally been derived from flows through the various channels in the vicinity, and that opening the Temaiku channel (assumed to be 225 m wide which is much wider than would have naturally occurred) would improve local circulation by around 11% and result in a slight reduction in residence time[4] in the area from 6.4 to 5.7 days. Opening up the any of the southern causeways would not have any noticeable impact on pollution levels in the south-eastern corner.

Royd (2006) provides a history of the Temaiku channel and its closure. Further modelling, albeit also using a relatively coarse model, suggested that opening the Temaiku channel would reduce pollution concentration by approximately 10% in the vicinity of the south-east corner of the lagoon.

[3] Based on an assumed mean lagoon volume of 2.1×10^9 m^3 (Damlamian and Webb, 2008)
[4] The average time a particle will remain in a particular area. Increasing flushing reduces residence time.

Damalian and Webb (2008) also carried out an initial assessment, using a much more detailed hydrodynamic model than the in the previous two studies, of residence time in various sections of the lagoon with and without the causeways for the four southern causeways and the Temaiku channel opened. This showed some significant reductions in residence time along the South Tarawa coast but caution needs to be expressed as the results look overly optimistic and may be related to:

- Wider openings being assumed at each channel than would be practical or would be maintained naturally. The inter-tidal channels on the south coast would have naturally, prior to causeway construction, been considerably narrower than the entire length of each causeway due to reef flat sand banks and sand spits that extended from each islet.

- A lack of reef/sand flat bathymetry and flow or tidal level measurements to ensure accurate representation of flow exchange through each channel.

As part of the Asian Development Bank / World Bank road upgrade project the design consultant will review opportunities for openings in the existing causeways to improve flushing, but currently there is no budget allocation or specific requirement for causeway opening to be included in the terms of reference.

3.2 Potential influence of channel flushing on public health and lagoon ecosystem outcomes

The above studies and observations indicate that flushing in Tarawa lagoon is dominated by the tide and the exchange of water over the western boundary. Whilst currents over, and in the vicinity of, the sand flats and southern part of the lagoon are low, over a tidal cycle a high level of flushing does occur due to the high tide range and twice daily exchange of water between the sand flats and the southern part of the lagoon.

In terms of pathogenic lagoon contamination and its effect on public health, the lagoon is only one of a range of pathways that result in people becoming ill (see Figure 3), albeit one that may be reasonably significant given the high levels of lagoon usage and consumption of shellfish. Despite the high tidal flushing overall that occurs each day over the sand flats, pathogenic faecal organisms become a human health risk as soon as they reach the water (Johannes et al, 1979). Hence flushing and dilution, to a low enough level to reduce health risks, would need to be near-instantaneous over the sand flats to reduce public health risks from contaminated lagoon water of South Tarawa. Given the contamination loads that are picked up by the rising tide each day and the distributed nature along the shoreline of this load, the small increases in flushing over the sand flats that would be achieved through opening up any or all of the causeways would not reduce contact or shellfish related-risk over the sand flats and would not make any discernable difference to public health outcomes.

The high level of tidal dilution and dispersion is the reason that in general nutrient-related problems, until recently, have not had a more detrimental impact on lagoon ecosystem health. However, the algal bloom that occurred last year does indicate that this situation is rapidly changing and that that nutrient loads entering the lagoon now (or under certain circumstances) exceed what can be effectively dispersed by lagoon flushing or taken up by the marine benthic biota in the southern part of the lagoon. If left unchecked and nutrients accumulate in sufficient concentrations for such algal blooms to continue or become more frequent, significant ecological damage will occur.

In improving lagoon ecosystem health, as with public health outcomes, addressing the sources of contamination, through effective water and sanitation provision and behavioural change to reduce the levels of contamination source, is the only way any substantive improvement can be made. However, lagoon residence times will have been increased due to causeway construction which is a factor (albeit a minor one relative to the source issues) in the nutrient-related issues now being seen. Increasing the flushing potential and reducing residence time, particularly in the south-east corner of the lagoon may have some limited positive benefits to the lagoon ecosystem in the short term. However, if the magnitude of the nutrient loads entering the lagoon are not significantly reduced, opening up some or all of the causeways will do nothing to stop significant lagoon ecosystem damage in the foreseeable future.

Over the next sections, each causeway is assessed for the potential to provide an opening for lagoon water quality improvement along with other opportunities, issues and risks noted.

3.3 Tanaea – Buota

3.3.1 Current situation

The channel between Tanaea and Buota is spanned by a single lane bridge with an opening of approximately 50 m. The bridge piers do not significantly constrict or reduce the flow of water, which for the majority of the time flows from ocean to lagoon. In 2008 the bridge suffered a partial collapse and became impassable for vehicles. A low causeway structure (Figure 8), to the ocean-side of the bridge, was constructed to enable vehicles to cross the channel during the lower part of the tidal cycle. However, this structure reduces the volume of water flowing through the channel, and blocks it completely over the lower part of the tidal cycle. With the repair of the bridge across the channel in 2009, the low causeway is now little used, falling in to disrepair, and presently is unlikely to be passable by vehicles.

Figure 8: Low causeway across the channel between Tanaea and Buota.

3.3.2 Opportunity, issues and risks

Removal of the low causeway structure would result in an increase in the volume of water flowing from ocean to lagoon particularly during the lower part of the tidal cycle. The increase in total volume will be relatively small but will have some slight incremental benefit by increasing input of 'clean' water in to the immediate sand flat and lagoon area, improving localised flushing and possibly local fish and shellfish environments, and reducing water temperatures in the channel.

Removal of the causeway has low environmental risk and low cost. The TUC Mayor does not consider there would be any community resistance to the removal of the low causeway. The causeway material would need to be removed from site with the potential to be crushed and used as construction fill.

3.4 Bonriki – Tanaea

3.4.1 Current situation

A single lane causeway connects Bonriki with Tanaea which completely blocks any flow of water through the channel between the ocean and lagoon[5]. The channel is split in to three sections for all but the highest tide levels by two raised conglomerate rock platforms that run parallel to the channel (Figure 9). Since the causeway was built sand has accreted in all three channels on both the ocean and lagoon sides and mangroves have established over the upper inter-tidal areas where accretion has occurred. On the Bonriki shoreline, residential property has developed over part of the accreted shoreline, with a reclaimed area and residential property now located along the lagoon-side of the southern coastline of Tanaea.

Figure 9: Key features of the Bonriki-Tanaea channel and causeway showing the three sections (numbered 1, 2 and 3) that make up the channel

[5] This, and the subsequent sections are based on a short paper discussing the opening up of the Bonriki-Tanaea causeway prepared by Arthur Webb (SOPAC) during an email-discussion between Farran Redfern (MELAD), Doug Ramsay (NIWA) and Arthur Webb (SOPAC) in September 2010.

At present upgrading the Bonriki-Tanaea causeway is not planned under the Asian Development Bank/World Bank road upgrade project with activities unlikely to extend any further north than the airport.

3.4.2 Opportunity, issues and risks

Installing culverts or a small Bailey bridge to re-establish a flow of water through the channel would, as with the channels to the north, likely result in a flow of water from the ocean to the lagoon for the majority of the time due to the effect of wave set-up on the ocean side reef. The volume of water flowing through any opening would be considerably less than that occurring through the Tanaea-Buota channel to the north. Water flowing through the channel is likely to reach the lagoon by joining the Tanaea-Buota channel to the west of Tanaea.

Opening up the entire causeway (i.e. all three channels) would result in erosion and shoreline adjustments occurring along both the Bonriki and Tanaea shorelines adjacent to the causeway. On the Bonriki side, a number of residential properties are now located on land that has accreted due to the influence of the causeway. If all of channel 1 was opened this land would be rapidly lost and property impacted. The southern coastline of Tanaea, particularly to the lagoon side of the causeway, has been substantially modified with a number of residential properties now located on a very vulnerable area of reclaimed land. Whilst addressing the long-term viability of this community in this location is an issue itself, opening up channel 3 would result in changes in the present shoreline.

To prevent potential erosion and readjustment of the shorelines of both Bonriki and Tanaea bordering the channel, if this causeway is to be opened, it is recommended that only the channel 2 (middle channel) and potentially around 10 m of the northern part of channel 1, adjacent to the raised conglomerate, be opened (Figure 10).

In opening up channel 2, some fringing mangroves that have established in both the ocean and lagoon sides of the channel adjacent to the causeway will be lost. There is potential to offset this loss with mangrove planting along both the Bonriki and Tanaea shorelines on the lagoon side of the causeway to help stabilise the shoreline bordering the channel

Re-establishing a flow of water through the channel will reduce water temperatures in the old channel and surround sand flats and will improve localised flushing and possibly local fish and shellfish environments.

Sand that has accreted in the channels due to the construction of the causeway is clean and well sorted and any sand excavated to re-open the channel could be used to meet a small amount of the top-fill requirements for the Sustainable Towns Project in Temaiku.

D R A F T

18/01/11

Figure 10: Potential culvert / bridge opening and summary of remedial activities at the Bonriki-Tanaea causeway.

3.5 Temaiku

3.5.1 Current situation

Re-establishing the opening at Temaiku has been discussed for many years with the history of the Temaiku channel closing and some of the socio-economic rational for opening summarised by Royds (1996).

Figure 11 shows the Temaiku area in 1943 prior to any reclamation and channel closure. At the ocean eastern end the channel had two openings, the main northern opening and a smaller one to the south, both of which appear limited in size due to the ocean beach blocking off much of the entrance. As with the channels to the north, the intertidal channel would have been relatively narrow (a few 10's of metres in places), and exchange of water limited. The flow would have dominantly been from ocean to lagoon, albeit with potential a slightly greater percentage of time with flow from the lagoon to the ocean than further north.

Figure 11: The Temaiku Bight area in 1943 (top) (Photograph courtesy of Dr Arthur Webb, SOPAC) and at present (bottom).

Due to the reclamation of the Temaiku area, the distance between the old ocean opening and the lagoon inter-tidal area is over 2 km, Figure 11. A large number of residential properties have been constructed, primarily along the naturally occurring flanks of the old channel but with a number over lower-lying reclaimed areas. Three causeways with access roads now cross the old channel. At the mouth of the northern channel, a number of seawalls and reclamations have occurred and the position of the shoreline has shown some changes. At the location of the old south channel, the road is prone to overwashing at high tides and moderate wave conditions.

3.5.2 Opportunity, issues and risks

Given the lack of circulation in the south-east corner of Tarawa lagoon re-establishing a flow through the Temaiku channel would have some positive impact on flushing of nutrients and reduction in residence time.

Dredging and reopening a channel of a similar width and depth as would have originally or naturally occurred would:

- Unlikely result in a significant exchange of water relative to that required to make any significant difference to overall flushing and lagoon ecosystem health in the south east corner, albeit some local benefits will occur within the Temaiku bight and immediate lagoon areas.

- May create an additional pollution source to the lagoon (via the channel) from contaminated groundwater due to inadequate septic facilities in the properties along the South Temaiku area.

- Have a significant capital cost given the amount of dredging required to create the channel. The likely capital cost will far outweigh any potentially achieved lagoon water quality benefits unless the dredge material was suitable to be used to raise land levels for the Sustainable Towns Project. Even so there may still be less expensive sources of sediment for this purpose, such as sand dredged from the lagoon.

- Require the relocation of more than 5 properties, removal of three causeways and construction of at least two bridges (one at the airport road and one on the Temaiku coast road), as well as potentially coastal protection along the adjacent shorelines along both the airport road and at the ocean side opening. There is a real risk that re-opening the channel may cause further shoreline change on the ocean side coast adjacent to the opening.

Opening up a larger channel (As an example, the extent of a 200 m wide channel is shown in Figure 12) through creating an artificially wide and maintained channel would increase the exchange of water between ocean and lagoon, improving flushing potential:

- This would require a substantially larger capital cost to create (including increased dredging and at least two substantial bridges, and engineering structures at the ocean entrance) and likely significant maintenance cost to maintain (there would be a tendency for sediment to move from the ocean side adjacent beach and reef flat in to the channel).

- Would have substantial greater impact (than a more naturally-sized channel) on shoreline change on the adjacent open ocean coastline.

- Would require the relocation of a large amount of residential property and a loss of a large amount of claimed and filled land.

Figure 12: Potential route of a channel at Temaiku (dashed white line) and potential approximate extent of a 200 m wide channel (red shading).

In improving flushing potential in the south-east corner every little will help. However, unlike the changes or opening to the two channels to the north described in the previous sections it is unlikely that the small improvements that can be achieved through opening up any size of channel at Temaiku are likely to be justifiable given the considerable capital costs, and potential social and environmental issues and risks, of doing so. Increasing flushing via the channels can only help ease the symptoms slightly but cannot provide an adequate solution to the lagoon nutrient problems in this south-east corner.

3.6 Temaiku - alternative

3.6.1 Current situation

An alternative to the old Temaiku channel proposed by the current Mayor of Teinainano Urban Council is to open up the narrow section of land between the ocean and lagoon at the southern end of the airport road at the eastern boundary of Bikenibeu (Figure 13). This would be a much shorter channel, and potentially less expensive to construct. No channel naturally occurred in this area.

On the ocean side, the proposed channel would intersect a long section of beach that stretches from Temaiku to beyond Tungaru Hospital, fronted by a relatively narrow fringing reef. On the lagoon side, the channel opening would enter the lagoon at the south-east corner of the Temaiku sand flats, in an extensive area of mangroves that is covered by water on only the highest part of the tidal cycle. This section of land from the hospital toward Temaiku is relatively densely populated.

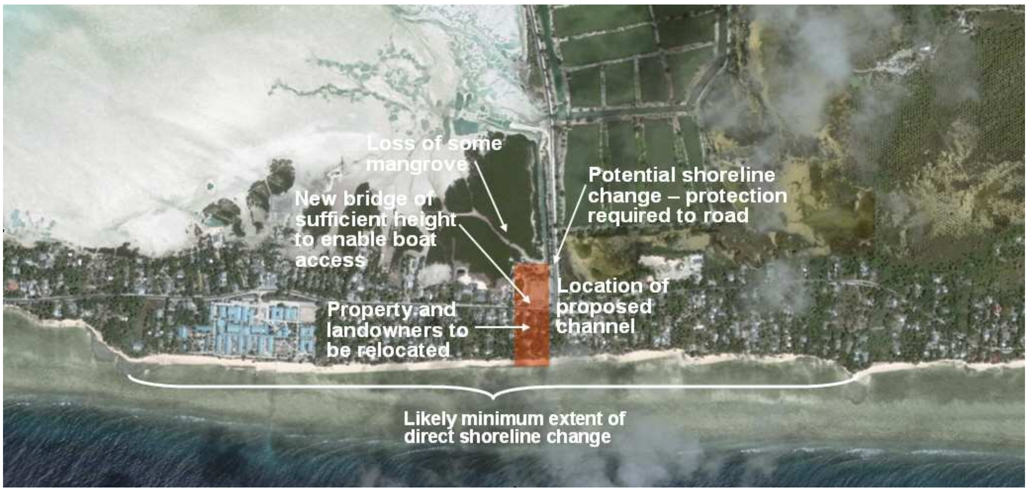

Figure 13: Location of proposed alternative Temaiku channel and summary of main issues and impacts.

3.6.2 Opportunities, issues and risks

The rationale for the artificial channel is to provide an alternative to the Temaiku channel that is shorter, and to provide potential ocean boat access for local fishermen at the eastern end of the island (rather than travelling all the way to Fishermen's

Channel at the Dia Nippon Causeway, or via the northern channels where ocean access is rare due to the wave conditions).

Unlike the channels to the north, where wave set-up on the ocean reef creates a dominant ocean to lagoon flow, along the south coast, such wave set-up will not have as significant a role. Rather it is likely that there will be an ocean to lagoon flow on part of the rising tide and lagoon to ocean flow a high tide and on the upper part of the falling tide. On the lower half of the tide there is unlikely to be any significant exchange of water through the channel. The volume of water that would flow through the channel in either direction over the upper part of the tide would not be all that substantial (relative to the daily flushing due to the rise and fall of the tide over the lagoon sand flats) and improved flushing would be fairly localised over the sand flats in the south-west corner.

There are a number of significant social and environmental risks associated with this option (Figure 13), including:

- A substantial number of residential property would need to be relocated to enable a channel to be created and a new road and pedestrian bridge constructed of sufficient height to enable boat access underneath at high tide.

- On the ocean side:

    - The channel would intercept the predominant east to west longshore movement of sand. This would likely cause substantial erosion and shoreline change along the adjacent ocean coastline.

    - It is likely that the channel would require periodic clearing to keep it open, particularly from sand transport in to it, or across the mouth, from the ocean side.

    - A significant amount of sand moved on to the reef flat due to lagoon to ocean flows through the channel would likely be lost off the edge of the reef. This would represent net loss of sand from the adjacent ocean side beaches furthering erosion potential, and would impact on the living coral at the edge of the reef.

    - Given the lack of any natural channel at the reef edge along this section, small boat access over the reef flat and outer reef is only likely to be possible on a high tide and when wave conditions are low. Access is unlikely to be possible for the majority of the time.

- On the lagoon side tidal channels created will result in a loss of mangroves and care would need to be taken to ensure that any such channels did not impact on the road to the airport or on development along the coastline immediately to the west of the channel entrance.

This is considered a very high risk option on both environmental and social grounds with the potential impacts far outweighing any environmental (i.e. minimal increase in flushing within the Temaiku Bight) or social benefits.

3.7 Ambo – Taborio

3.7.1 Current situation

The opening between Taborio and Ambo was the only natural opening along the approximate 17 km section of South Tarawa between Temaiku and Taeoraereke. Prior to the causeway being constructed the opening was likely to have been a narrow channel or channels through inter-tidal sand banks, with a spit extending east from the eastern end of Ambo (hence relatively easy to construct a causeway closing the opening). On the ocean side, a number of offshore islets provide shelter, with the inner part of the reef ponding at low tide. The sheltered nature, sand covered inner-reef flat, and likely nutrient input from the high level of usage of the ocean beach as a toilet along the Taborio coast, results in the only patches of seagrass found on the ocean side of South Tarawa.

The closure of the opening has resulted in accretion of land, along the length of the causeway on the lagoon side (which is now state land) and along the adjacent Ambo lagoon shoreline (upon which some residential property is now located). At the eastern (Taborio) end of the causeway, the reclamation and development along the Taborio lagoon shoreline, and tendency for the net movement of beach sediment along this section of lagoon to be to the west, results in a narrower strip of land between the road and the lagoon beach and for the shoreline to be more prone to periods of erosion and change. This area was identified as one of the priority areas for shoreline protection under Phase II of the Kiribati Adaptation Project with an approximately 280 m in length section of seawall recently constructed (Figure 14).

Figure 14: Location of Ambo causeway and summary of main issues and impacts.

D R A F T 18/01/11

3.7.2 Opportunities, issues and risks

Given the lack of natural openings along the section of coast between Temaiku and Taeoraereke, the level of direct use of the beach and lagoon as a toilet and direct pollution of groundwater due to the lack of any reticulated sewer system between Bikenibeu and Taeoraereke, improving flushing could be expected to have a more significant impact than some of the other causeway locations.

Furthermore if the opening was large and high enough to allow local small fishing boats to pass between the lagoon and ocean sides on the upper part of the tide, it would substantially cut the time and distance for ocean access, compared to travelling all the way to the Fisherman's Channel at the Dai Nippon Causeway. There would appear to be at least a couple of natural channels across the outer reef which could enable boat passage under low wave conditions, albeit the amount of time that wave conditions would be safe enough to cross this section of reef will be less than at the Fisherman's channel.

As with other channels along the South Tarawa coastline there is unlikely to be any significant difference in water levels between the ocean and the lagoon side (Section 3.2) throughout the tidal cycle, albeit the differences at Ambo causeway are likely to be slightly greater than further west due to a slight lag in tide and small amount of tide range amplification. Hence the potential net interchange of water through any opening, irrespective of the width, is unlikely to be significant, with a slightly greater flow likely from lagoon to ocean, particularly during the normal north-easterly wind conditions. Any change in flushing will again be relatively local and limited to the immediate Taborio/Ambo sandflat area. However, there are two issues which will influence the degree of flushing:

- The reef flat on the ocean side ponds on the lower part of the tide cycle. At high tide and first half of the falling tide, water will tend to flow from the lagoon to the ocean-side reef flat, with water flowing off the ocean reef flat to the ocean. However, on the lower part of the falling tide and first half of the rising tide there is less interchange between the ocean-side reef flat and the ocean resulting in water flowing from the ponding ocean reef flat back in to the lagoon. This further limits the amount of water from the lagoon that is transferred to the open ocean, or the amount of 'clean' ocean water that is transferred to the lagoon during a tidal cycle. This is summarised in Figure 15.

- As the ocean beach is extensively used as a toilet, at least along the Taborio shoreline, contaminant levels on the ocean-side reef flat may not be significantly different to that in the lagoon.

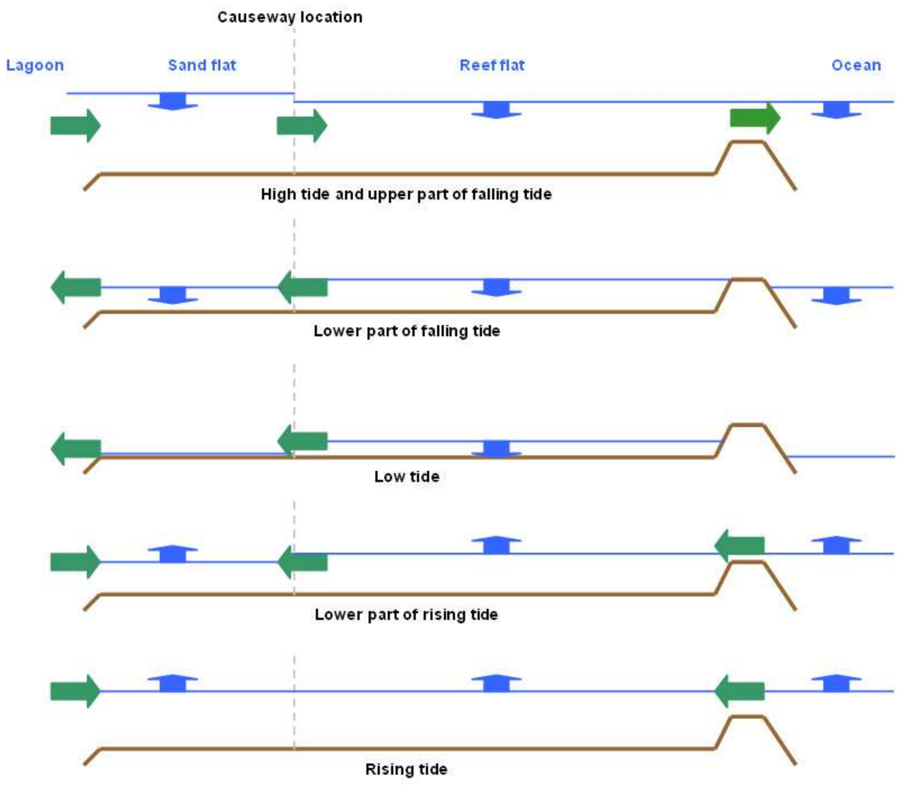

Figure 15: Summary of flow directions (green arrows) between the lagoon, lagoon sand flats, ocean side reef flat and ocean during a spring tidal cycle under typical weather conditions through an opening in any of the channels along the South Tarawa coastline.

Any opening will tend to result in a net movement (i.e. loss) of sand from the lagoon to ocean reef-flat side with the impact of this in terms of shoreline change and erosion depending on the location and size of the opening.

Whilst the magnitude of any flushing will increase with the size of the opening through the causeway, opening up the channel to the width prior to the causeway being built, or a lesser width located to the west of the new KAP seawall would result in substantial shoreline change and loss of land to the west along the Ambo lagoon and eastern ocean-side frontage (Figure 14).

To limit the shoreline impacts (and if enabling small boat passage was important), opening a short section at the eastern end of the causeway could be considered. This would require removal of a section of the newly completed KAP seawall but would likely have least negative impact on shoreline changes as the lagoon shoreline along the Taboroi frontage is largely reclaimed and the remainder of the KAP seawall would limit the most significant impacts to the west. However, there would still be some erosion potential to the west of the wall / eastern end of Ambo due to a loss of sand through the opening to the ocean side. This movement of sediment may also have a detrimental impact on the seagrass beds located on the inner section of the ocean side reef.

Given the limited width if a culvert or small bridge was installed, any improvements in water quality in the vicinity are likely to be minimal.

3.8 Bairiki-Nanakai-Taeoraereke

3.8.1 Current situation

The causeways between Bairiki and Nanakai, and Nanakai to Taeoraereke (Anderson Causeway), were constructed in the early 1960s. As with the Ambo causeway sand spits extending from the islets would have formed the foundation of the causeway with the width of the inter-tidal channel(s) relatively narrow. Since construction there has been a build up of land on the lagoon side of both causeways, which will have also built up the shoreline along the coastlines of both Nanakai and Bairiki, and some significant changes in shoreline position on the ocean side of Nanakai, albeit some of which are due to other human activities and not as a result of the causeway, Figure 16. A detailed assessment of the changes and processes causing these changes is provided by Webb, (2005).

The Nanakai waste dump is located on the lagoon side between Taeoraereke and Nanakai along with a telecommunication mast and associated building. On the ocean side a seawall protects the eastern (Taeorareke) end of the causeway to just beyond the location of the dump. At the western end of Nanakai a new seawall has been built as part of Phase II on the Kiribati Adaptation Project, with a short section of ad hoc seawall also located on ocean side, Figure 17.

Both ocean side reef flats pond at low tide albeit it not to quite the same depth as at Ambo.

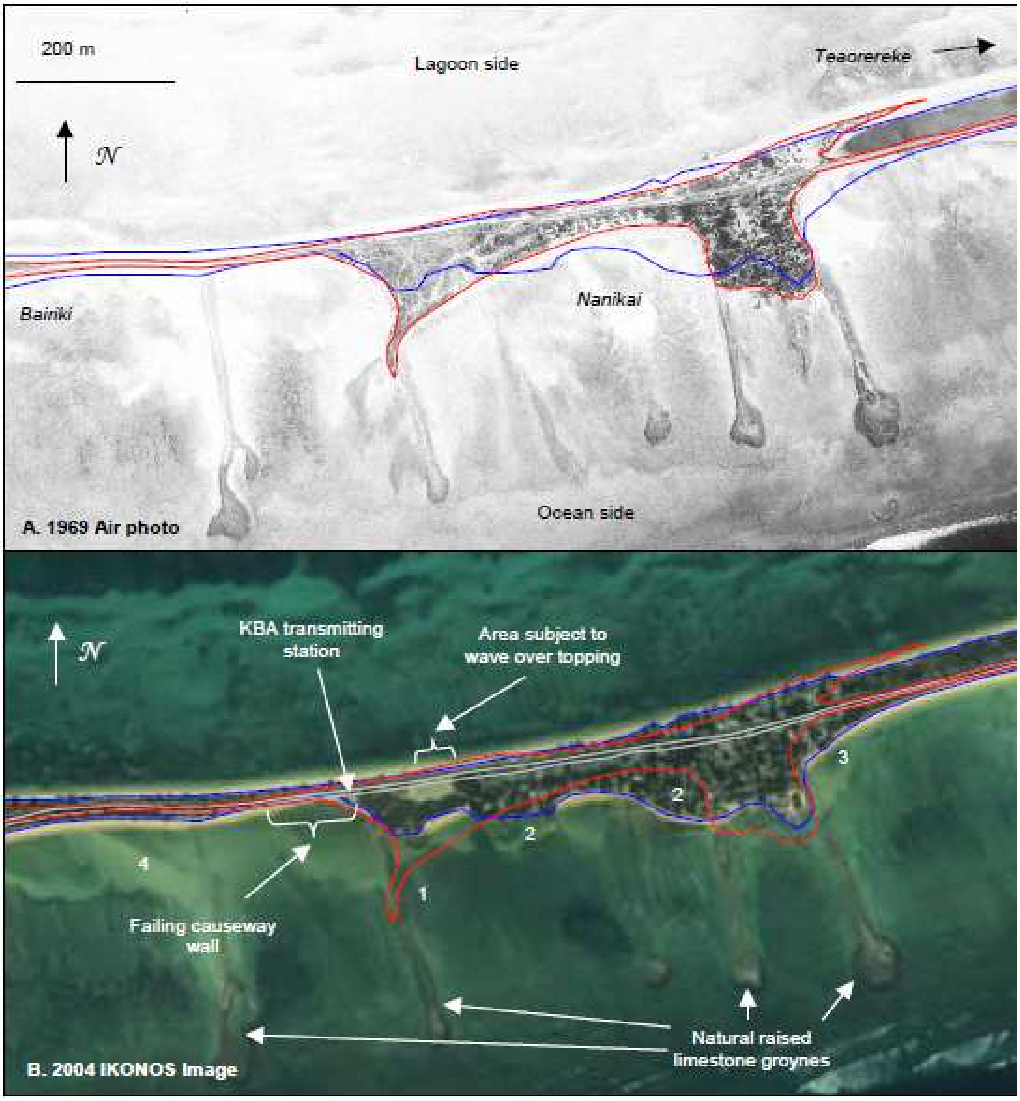

Figure 16: Shoreline changes at Nanakai between 1969 (top photograph / red line) and 2004 (bottom photograph / blue line), (Webb, 2005).

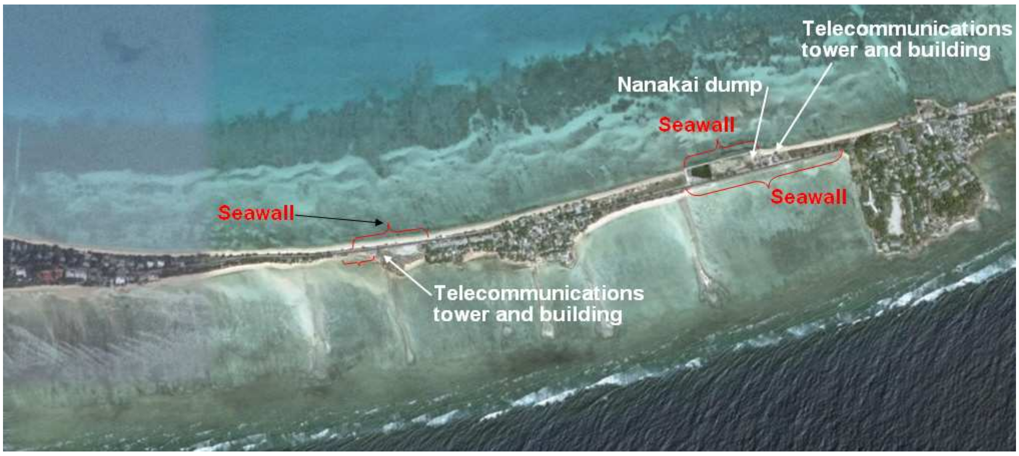

Figure 17: Bairiki and Nanakai, and Nanakai to Taeoraereke (Andersen) causeways.

D R A F T 18/01/11

3.8.2 Opportunities, issues and risks

Most of the same considerations and issues discussed in Section 3.6 for the Ambo causeway are relevant here, in particular:

- The exchange of water through any opening will not be substantial relative to the effects of lagoon tidal flushing and will follow a similar pattern to that shown in Figure 15. Flushing, where nutrient enriched lagoon water is removed to the open ocean, or where 'clean' ocean water enters the lagoon is likely to be limited under normally occurring weather conditions. Hence, as with the other openings, any water quality improvements are likely to be localised. It is unlikely that any opening would have any significant influence on the localised trapping of polluted water east of Bairiki harbour.

- Creating an opening in ether of the causeways would potentially result in significant shoreline change due to the net loss of sand from the lagoon to the ocean side via the opening and the impact any opening would have on beach and lagoon sediment being transported alongshore. Engineering structures would need to stabilise the entrance and immediate shoreline but negative impacts will still be experienced:
    - Any opening to the east of Nanakai dump will result in direct shoreline changes on the lagoon side between Taeoraereke maneaba and the dump. Due to the influence on longshore sediment movements it may also affect the shoreline to the west of the dump.

- Any opening to the east of the dump will result is substantial shoreline change along both the lagoon and ocean side of Nanakai which on the lagoon side may extend some considerable distance towards Bairiki.

- Tidal current through and adjacent to any opening close to the dump could result in increased dispersion of litter and leachate (albeit at present there is little indication that heavy metal or nutrient leachate from the dump is a significiant issue), both on the lagoon and ocean side.

- Between Nanakai and Bairiki any opening would logicially be located to the immediate west of the new KAP sea wall. However, potential shoreline change could extend some considerable distance along both the lagoon and ocean shoreline of Bairiki to the west.

3.9 Dai Nippon Causeway

3.9.1 Current situation

Since the construction of the Dai Nippon causeway in 1987 there has been a build up of land along both ocean and lagoon shorelines of Betio, Figure 17. The lagoon shoreline has also built out and to the west along the causeway from Bairiki.

Fishermen's channel intercepts beach sediment moving along the lagoon-side of the causeway and sand flats. Whilst sediment will be moved in both directions there is likely to be a net movement to the west from Bairiki. There is also a general net movement of sediment out (i.e. loss) through Fisherman's channel towards the ocean. As a result the channel is largely filled in (and has been cleared on a number of occasions), particularly on the lagoon side, with both a flood and ebb shoal currently located some 30 or 40 m from the opening under the causeway (Figure 18). Only under and adjacent to the bridge, where flow velocities can be strong due to the constriction of the opening under the causeway, and towards parts of the channel towards the ocean is the channel currently navigable at all stages of the tide. The width of the opening under the causeway is currently not wide enough to enable passage of the inter-island ferry boats to Maiana.

As with the other natural opening along South Tarawa, prior to the causeway being built exchange of water between lagoon and ocean-side reef flat would have been via a number of narrow inter-tidal channels between sand banks and bars (Figure 19).

Figure 17: Shoreline changes at Betio between 1943 and 2004 (Webb, 2010).

Figure 18: Fisherman's channel over the ocean side reef. The ebb shoal can be seen in the middle of the picture along with the two main flow paths in to the channel that drain the ponding reef flat at low tide.

Figure 19: Looking east over Betio towards Bairiki and Taeoraereke in 1944. The many intertidal sand bars and banks with narrow channels in between can be seen between Betio and Bairiki (Photo source: http://www.tarawaontheweb.org/overview.jpg).

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The ocean-side reef flat ponds during the lower part of tide cycle. This influences the flow direction through the causeway opening at Fisherman's channel. Figure 20 summarises flow direction and indicative current magnitudes during a Spring tide on 6 November 2010, with a similar pattern as that described in Figure 15. Wind conditions were from the east and typical of conditions normally experienced on Tarawa.

Over the lower half of the falling tide and at low tide water flows off the ocean-side reef flat in to Fisherman's channel and both back in to the lagoon and out to the ocean via the channel. As the tide rises on the ocean side it leads the tide level in the lagoon resulting in a period of strong flow through the channel in to the lagoon. As the tide approaches high tide, slight amplification of the tide in the lagoon, and north-easterly wind effects result in a reversal of the current through the channel which continue during the falling tide until the reef ridge on the ocean side becomes exposed and the ocean side reef flat begins to pond.

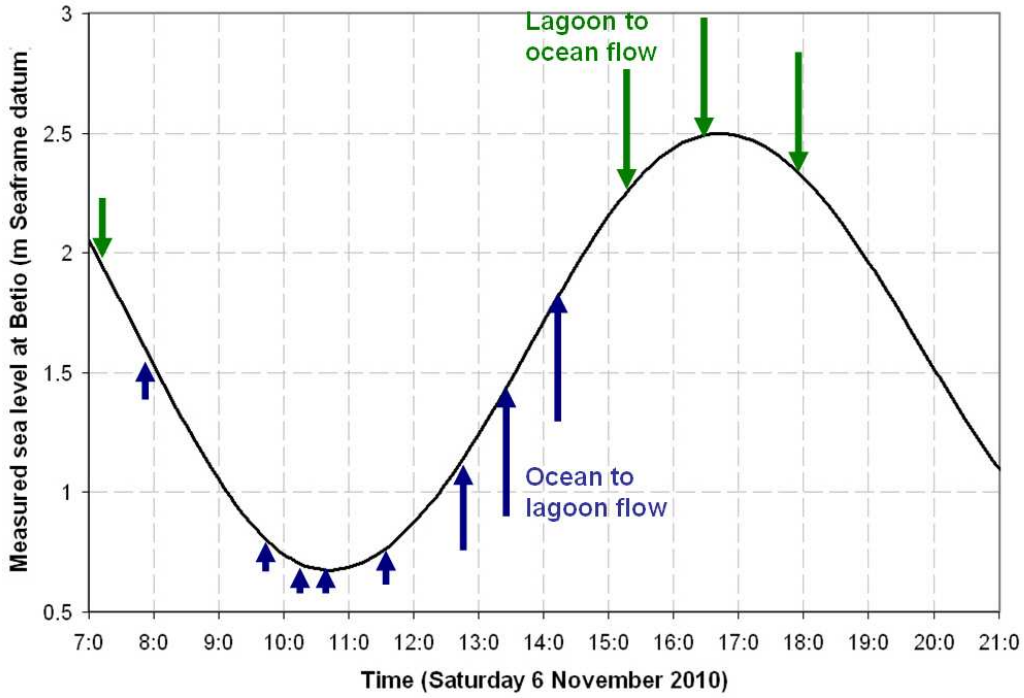

Figure 20: Sea levels at Betio during Saturday 6 November 2010 and flow directions through Fishermen's Channel at various times during the day. The size of the arrow is indicative of the current speed through the opening.

Along parts of the causeway, repairs have had to be carried out due to a loss of the causeway core material through fine sediment within the core being winnowed out between cracks and holes in the outer armouring This has resulting in various repairs being carried out along mainly ocean-facing sections, notably at the curve in the causeway towards the Bairiki end. As part of the ADB/World Bank road project investigations will be conducted as to the integrity of the causeway core but there is concern that there may be considerable sections of the causeway with voids and core material lost (Moanataake Beiabure, Pers Comm).

Discharges from the ocean outfall at Bairiki and Betio are know to result in surface plumes that are (under certain conditions) likely to be transported back onshore and over the ocean-side reef flat, and in the case of the Bairiki outfall, over the reef flat along the eastern end of the causeway.

3.9.2 Opportunities, issues and risks

Given the very minor difference in tide levels between the ocean and lagoon side, and the lack of any frequent high wave conditions on the ocean side there is little to force any significant net exchange of water through the causeway. Hence it is unlikely that any significant reduction in nutrient concentrations will be achieved along the more populated sections of South Tarawa or at Betio from opening up further channels or culverts through the causeway. However, some improvement could be achieved over the sand flats adjacent to the causeway (albeit these areas tend to be less polluted than further east) and in the lagoon areas to the north-west of Bairiki which the SOPAC modelling (Damlamian and Webb (2006) shows tidal currents to be relatively sluggish:

To enable ferry access there is a desire to widen the opening at Fisherman's channel. It is suggested that this is only widened as much as is necessary to navigate the ferry vessels safely through the opening at peak tidal flows. Maintaining a relatively narrow with of channel ensures that the tidal flows can continue to maintain the channel under and immediately adjacent to the opening from sedimentation enabling boat access at all stages of the tide. To enable improved height access would require the underside of the bridge to be raised.

If further culverts or bridge opening are created it is suggested that these be located over the central section of the causeway and not too close to where land is building up on the lagoon sides at both Bairiki and Betio (Figure 21). The costs of installing culverts or further sections of bridge are unlikely to be justifiable on the small improvements in water circulation and nutrient flushing alone. However, if the causeway surveys being carried out as part of the ADB/World Bank road project identify large voids in the causeway replacing such sections with culverts or wider openings could be feasible.

Openings located east of fisherman's channel are likely to have a slightly greater flushing impact. However, they will intercept sand that is being moved in a westerly direction along the lagoon side of the causeway with a net loss of sand out the opening and on to the ocean reef flat. This may reduce the potential for sand filling up the Fisherman's channel but would resort in a loss (or at least less accessible) of a source of construction sand which is frequently gathered from along the lagoon side of the causeway to the east of Fisherman's channel.

The low current velocities through the opening at fisherman's channel at low tide show that there would little benefit from dredging deeper channels through the causeway, which in any case would largely fill with sand. Opening up further channels across the entire ocean side reef flat to the ocean are not recommended.

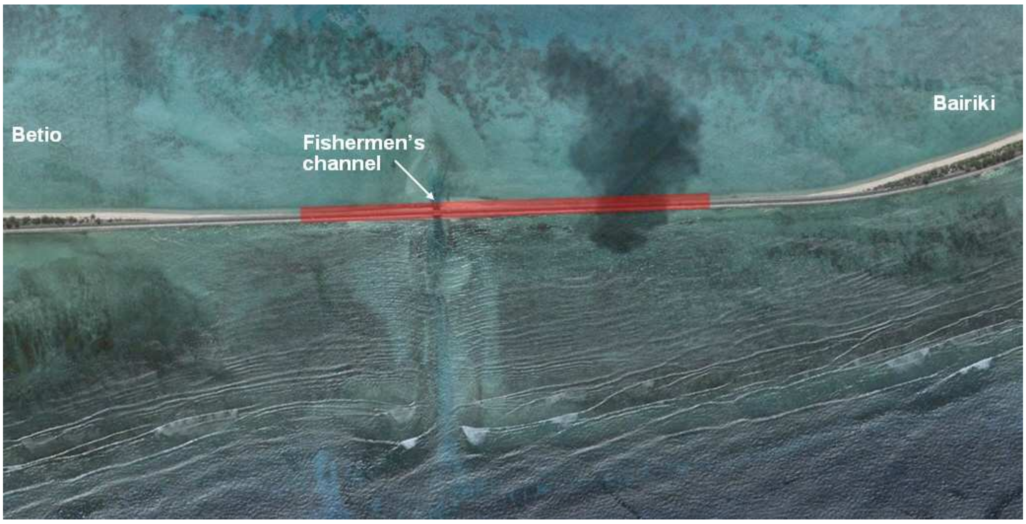

Figure 21: Location (shaded red area) where further culverts of bridge sections could be considered along the Dai Nippon causeway.

4. Impact of other ongoing or planned development activities

There are a range of other developmental activities planned for South Tarawa over the next few years, a number of which are directly relevant to water and sanitation-related public or lagoon ecosystem health outcomes.

At present within the Asian Development Bank / World Bank road upgrade project, which extends from the western end of the Dai Nippon causeway to the Airport (excluding Bairiki), there is no specific requirement to construct openings in any of the existing causeways to improve flushing. Rather the terms of reference will require the design consultant to review the opportunities as part of their design report.

Under the Kiribati Adapation Project Phase III, the draft Project Appraisal Document indicates that the focus will be on continue to strengthen the government capacity and improving the management and governance of water resources and infrastructure. Whilst improved public-health outcomes would be expected from the planned development of the groundwater abstraction systems, reticulation management, rainwater harvesting, community behaviour and governance and management activities, the project is unlikely to have any impact on improving lagoon water quality and associate human and ecosystem issues.

The most significant potential for improved human and lagoon ecosystem health of the currently planned activites is likely to occur under the two MFAT-IDG coordinated projects:

- The proposed Betio and Bairiki Peri-Urban Slum Upgrading project (Teinainano Urban Council and Betio Town Council, 2010) where new household sanitation facilities are planned for 630 plots and improvements to the area-wide existing and new sewers planned for 1000 plots in Betio and Bairiki.

- The first phase of the Sustainable Towns Project (NZAid, 2010) where 150 new plots are planned for the first Temaiku subdivision.

Both schemes intend to use a bucket flush system in each household connected to a closed household septic tank with the liquid effluent from the septic tanks being transported through small-bore flat grade shallow sewers for disposal out the existing outfalls (in the case of Betio and Bairiki) and via a new outfall on the southern / south-eastern coastline for Temaiku.

This approach has the advantage in that it can break two of the most significant human-related lagoon contamination pathways (Figure 3) by: 1) removing a significant source of groundwater faecal and nutrient contamination (leakages apart), and 2) improved access to toilet facilities thereby reducing the use of the beach or bush, assuming health promotion activities are effective and result in the use of the new toilets in each household becoming the dominant sanitation practice.

However, care will needed not to transfer problems to the ocean side. There is already evidence, likely due to the use of brackish water, rather than salt water, to flush in the three reticulated sewer systems of significant nutrient-related problems leading to coral being replaced by algae and associated negative biodiversity changes in the vicinity of the outfalls. With the limited water depth of the ocean outfall (10 m), and the release of more buoyant brackish water from the outfall, there is considerable potential for surface plumes moving back over the ocean fringing reef resulting an increased risk of human contact with contaminated water along ocean-side sections adjacent to the outfalls. There is some evidence of this happening at Betio and Bairiki and surface plumes of discoloured water have also been noted at the hospital outfall.

In terms of reducing the potential environmental and human-health risk impacts on the ocean side from effluent discharged from the outfalls, the most effective solution would be to have a saltwater system (which results in initial dilution and dispersion occurring in deeper water rather than close to or at the surface) discharging at a deeper water depth (25 to 30m) away from the area where most coral growth occurs. However, it is appreciated that the saltwater system comes with increased on-land operational issues and the pour-flush system has a much better likelihood of remaining operational.

No detailed assessment has been done as to initial dilution and dispersion performance from any of the outfalls and the impact this may have on water quality on the surrounding ocean side reef flat, and on the reef ecosystem. As going forward, ocean disposal is likely to be the main approach to sewage disposal if both water-borne related public health and lagoon ecosystem problems are to be significantly reduced, the impact of increasing sewage disposal to the ocean-side needs to be assessed to establish the potential impact this will have on the surrounding reef ecology and whether, or under what conditions, sewage plumes could come back onshore and create a public health risk. As part of any such assessment this would need to investigate:

- Whether it would be better to have many small outfalls, e.g. an additional one servicing the Temaiku area (and other areas currently without reticulated sewage), or whether to limit the number and increase the outflow from the existing outfalls. For a saltwater system it would likely be preferable to have an increased number of small outfalls but this may not necessarily the case where brackish water is being released.

- The effect of extend the outfalls in to deeper water on dilution and dispersion

- If plume dispersal would result in negative human or environmental impacts what other options could assist, for example the possibility of diluting sewage outflow with more dense seawater at the landward end of the outfall to reduce the potential for a buoyant plume, or whether the sewage could be released at certain times, e.g. during a falling tide and when winds are blowing offshore.

The endorsement of National Water Resource Policy by the Kiribati Government in 2009, and with the draft National Sanitation Policy currently under consideration, there is likely to be further investment in improving water and sanitation infrastructure in South Tarawa. Assuming the same approach as is being consider in the two projects above for the main peri-urban areas, of a toilet for each household, health promotion activities to promote behavioural change, prevention of human waste reaching and contaminating groundwater, and removal of nutrient and/or pathogen rich effluent for ocean disposal this will have significantly greater influence on reducing many of the human health and lagoon ecosystem contamination pathways summarised in Figure 3, and considerably more effective than can be achieved through increased flushing of the lagoon.

5. Conclusions

This report was prepared to summarise what is known about the current state of pollution in Tarawa lagoon, the effect this has on both public and lagoon ecosystem health, and whether opening installing causeways or openings in existing causeways would improve flushing of the lagoon, and have a positive impact on both the considerable human and ecosystem health-related problems being experienced.

On South Tarawa there are a wide range of human and animal waste-related contamination sources and a wide number of contamination pathways. Virtually every sanitation system or practice currently in place in South Tarawa contributes to contamination of the groundwater and / or immediate coastal waters in some way.

Where the lagoon or ocean coastal waters forms part of the contamination pathway, there are two main mechanisms that can result in human-related public health issues: 1) contact with contaminated seawater, and 2) consumption of contaminated shellfish. Faecal contamination of both lagoon water close to the shoreline, and shellfish flesh have in general (and excessively so) exceed safe levels for some considerable time. Whilst there is no information on the relative influences of the various contamination pathways resulting in human health issues, both of these are likely to be significant given the number of I-Kiribati who bathe or swim in the lagoon each day, and the amount of shellfish that are collected for consumption.

Past assessments of nutrient levels in the lagoon had concluded that the high level of tidal flushing and uptake by the benthic biota in South Tarawa was sufficient to assimilate the levels of natural and waste-related nutrients entering the lagoon. However, the algal bloom that occurred in December 2009/January 2010 does indicate that this situation is rapidly changing and that that nutrient loads entering the lagoon now (or under certain circumstances) exceed what can be effectively dispersed by lagoon flushing or taken up by the marine benthic biota in the southern part of the lagoon. If left unchecked and nutrients accumulate in sufficient concentrations for such algal blooms to continue or become more frequent, significant ecological damage will occur.

Flushing in Tarawa lagoon is dominated by the tide and the exchange of water over the western boundary. Whilst currents over, and in the vicinity of, the sand flats and southern part of the lagoon are low, over a tidal cycle a high level of flushing does occur due to the high tide range and twice daily exchange of water between the sand flats and the southern part of the lagoon.

In contrast very little water exchange, relative to tidal flushing, occurs through any of the open channels in South Tarawa or would have occurred through any of the original causeway openings.

Despite the high tidal flushing overall that occurs each day over the lagoon sand flats, pathogenic faecal organisms become a human health risk as soon as they reach the water. Hence flushing and dilution, to a low enough level to reduce health risks, would need to be near-instantaneous over the sand flats to reduce public health risks from contaminated lagoon water of South Tarawa. Given the contamination loads that are picked up by the rising tide each day and the distributed nature along the shoreline of this load, the small increases in flushing over the sand flats that would be achieved through opening up any or all of the causeways would not reduce contact or shellfish-related health risk over the sand flats and would not make any discernable difference to public health outcomes.

In terms of nutrient concentrations, causeways construction will have been a factor in the lagoon ecosystem health issues now beginning to be seen (albeit a minor one relative to the source issues). Increasing the flushing potential and reducing residence time, particularly in the south-east corner of the lagoon may have some limited positive benefits to the lagoon ecosystem in the short term. However, if the magnitude of the nutrient loads entering the lagoon are not significantly reduced, opening up some or all of the causeways will do nothing to stop significant lagoon ecosystem damage in the foreseeable future.

Whilst improving flushing potential in the south-east corner every little will help, it is unlikely that the cost of doing so would justify the small improvements that could be achieved. Only increasing the flow through the Tanea-Buota channel and opening up part of the Bonriki to Tanaea causeway, are the costs likely to be low enough to consider.

Creating openings in the causeways along the central to western part of South Tarawa (between Taborio and Ambo, Taeoraereke to Nanakai to Bairki, and also at Temaiku) will result in limited exchange of water and flushing of either nutrient rich lagoon water reaching the ocean, or ‘clean water from the ocean reaching the lagoon. Openings in any of these causeways will have the potential of causing significant shoreline changes.

In improving lagoon ecosystem health, as with public health outcomes, addressing the sources of contamination, through effective water and sanitation provision and behavioural change, is the only way any substantive improvement can be made. Such improvements will not be achieved through increased flushing. Not only would this reduce the contamination pathways via the lagoon, but also address most of the other potential pathways as well. The approach planned for the Betio and Bairiki Peri-Urban Slum Upgrading and first phase of the subdivision at Temaiku under the Sustainable Towns project would appear to provide an effective approach. However, care needs to be taken to ensure the effluent disposal via the existing and any new ocean outfalls are properly assessed and constructed to prevent potential human-health and reef ecology impacts being moved to the ocean side coast.

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7. Appendix 1: Terms of reference

Objective
Provide advice on the potential of increasing circulation in Tarawa lagoon as a means of improve lagoon water quality and associated public health in South Tarawa, Kiribati.

Key deliverables or outputs

1. Submit a Draft Report to the MFAT Development Programme Manager – Kiribati that sets out, clearly and succinctly, the information, findings and recommendations resulting from the performance of the task above. The MFAT Development Programme Manager – Kiribati will gather feedback on the draft report from other stakeholders.

2. Submit a Final Report, which covers the same content as the Draft Report but in a manner that also addresses any feedback on the draft report from MFAT and other stakeholders.

Specific tasks the Supplier must complete
Prior to visiting Kiribati, the Supplier will:

1 Refamiliarise as necessary with previous water quality studies.

2 Review documents provided by MFAT of the World Bank's South Tarawa Road Rehabilitation Project, and liaise with the World Bank and the Kiribati Ministry of Public Works and Utilities (MPWU) regarding the project:

- World Bank contact: Chris Bennett, cbennett2@worldbank.org)
- MPWU contact: Moanataake Beiabure, moanataakebeiabure@yahoo.com,au

3 Review the Sustainable Towns Programme Design document, and other key NZ Aid Programme Urban Development programme documents (eg. Solid Waste Management report and follow-up solid-waste management activities planned and underway; Temaiku subdivision documents).

4 Research and review other documentation as related to the objective and provided by the MFAT Development Programme Manager (Kiribati) e.g. pacific Infrastructure Advisory Centre (PIAC) Action Plan for the South Tarawa Water, Sanitation and Solid Waste improvement programme; relevant Kiribati adaptation Project (KAP) II and proposed KAP III documents, and liaise with the World Bank (Milina Battaglini) and Ministry of Environment, Lands and Agriculture Development (MELAD) (Teiti Erikate).

5 Prepare (i) a brief synopsis of what is known about the current state of the lagoon (water quality and eco-systems) based on existing data, highlighting if possible particular parts of the lagoon most at risk; (ii) summarise what is known about the various pollution sources and their potential impact on lagoon water quality and associated public health; and (iii) a summary of all relevant activities currently being or about to be undertaken.

The Supplier will visit Tarawa from 4 – 9 November (including working Saturday). During the Visit, the Supplier will:

6 Meet with stakeholders (time permitting, and where relevant and available) and ascertain their views and priorities (e.g. MPWU, NZ High Commissioner, Teinainano Urban and Betio Town Council Mayors, KAPII, MELAD, the MFAT Development Programme Manager (Kiribati), Kiribati Port Authority, and Urban Development contractors). The NZHC will help set up meetings on request.

7 Assess the likely impact on lagoon water quality of other proposed infrastructural initiatives in South Tarawa over the next two – three years (eg. MFAT / Government of Kiribati Urban Development Programme activities; World Bank KAP III activities and South Tarawa Road Rehabilitation etc). Provide recommendations for any improvements that could be made to these proposed activities that would assist with improving lagoon water quality, or mitigate increased lagoon water pollution.

8 Provide a qualitative assessment of each causeway / lagoon opening in South Tarawa[6] and report on the impact that opening up the causeway or other associated activities (e.g. dredging the existing fisherman's channel, new dredged channels) will have on improving lagoon water quality (if any) and identify any other likely impacts / issues.

9 Where the World Bank is proposing culverts in causeways, the assessment should be based on what the World Bank is proposing. Where necessary, make recommendations on how the detailed design work to be undertaken on this Roads project might be focussed to ensure maximum positive impact of planned structural solutions.

10 For areas outside of the focus of the World Bank roads project: Advise if there are any areas where it is assessed that increasing water flow between the ocean and lagoon would have a significant impact on improving lagoon water quality, with minimal or manageable risk. Provide a concept note of the actions and likely resources required. Priority should be given to low cost options.

11 Provide advice on whether improving lagoon circulation will improve water quality in the lagoon and thereby improving public health in relation to other infrastructure related (water and sanitation) activities and initatives.

12 Identify any potential opportunities not currently planned by NZ Aid Programme Urban Development activities, GoK's Sustainable Towns Programme or KAP II and KAP III that if implemented would assist in improving lagoon water quality and public health where particularly at risk.

13 Provide a detailed note of the actions and likely resources required to implement any options identified from the above Tasks.

[6] No causeways or routes north of Bonriki airport are to be considered given the high risk of squatting on protected water lens areas if roads are upgraded north of the airport.

8. Appendix 2: Visit schedule (November 2010)

Wednesday 3 November	Depart Hamilton, NZ and fly to Nadi, Fiji. Overnight in Nadi
Thursday 4 November	Arrive Tarawa at 8:30 am on Flight FJ230.
	Brief meeting with Farran Redfern, MELAD at airport
	Meeting Tareri Abete-Reema, Director, MELAD (10 am)
	Meeting with MELAD water quality staff (11:30 am)
	Visit to Fishermen's Channel on the Dai Nippon (Bairiki – Betio) Causeway.
Friday 5 November	Meeting with Rob Kaiwai, NZHC (10 am)
	Meeting with Moanataake Beiabure, MPWU (2 pm)
	Meeting with KAP Project team and World Bank (5 pm)
Saturday 6 November	Visual monitoring of flows through the Fiserman's channel and low and high tide assessment of the Dai Nippon, Bairiki to Nanakai and Nanakai to Taeoraereke causeways
Sunday 7 November	Visit at low and high tide to the Ambo and eastern causeways and channels
Monday 8 November	Meeting with Tokia Creig, Teinainano Urban Council
	Meeting with Koria Tamuera, Kiribati Port Authority
	Meeting with Mrs. Rubee Eromanga, Kiribati Port Authority
Tuesday 9 November	Meeting with Ms Beia Tiim, Environmental Health (9 am)
	Meeting with Kiribati Meteorological Service (1 pm)
	Meeting with Sustainable Towns Project team (4 pm)
Wednesday 10 November	Meeting with Rob Kaiwai, NZHC (10 am)
	Water Quality Committee Meeting, (2-4 pm), Ministry of Public Works Utilities.
Thursday 11 November	Depart Tarawa on Flight FJ231 and fly to Auckland via Nadi, Fiji. Drive back to Hamilton.