Rehabilitation, Monitoring and Extension of Landfills in an Atoll Environment.

Alice Leney[1 *], Harry Langley[2]

[1] Programme Manager, Kiribati Solid Waste Management Programme; Ministry of Environment, Lands and Agricultural Development, Kiribati.
[2] Waste Disposal Officer, Kiribati Solid Waste Management Programme; Ministry of Environment, Lands and Agricultural Development, Kiribati.
[*] a.leney@melad.gov.ki ; alice@coolcard.co.nz .

Abstract

Kiribati is an atoll nation; there are three controlled landfills only, present in the capital Tarawa, where they are built into the tidal lagoon sand flats. The construction of the landfills is simple, and no liners are used, being a sand berm covered with a concrete skin. Water testing at a various intervals over the last decade indicates that pollution from landfills is better than might be expected, and studies of the water movement indicate that the coral sand - calcium carbonate - is treating the leachate to provide an interesting Nature-Based Solution to the problem of leachate management, a point learned at APLAS 2012. However, when the landfills were built in the early 2000's this information was not available to the builders. Two of the three landfills are now full, and extensions need to be built. The information from studying the landfills can now be used to feed into a new design of landfill that will be suitable for atoll locations without costly and vulnerable leachate treatment systems. A full landfill on Tarawa has been rehabilitated to provide usable land that is some of the highest in the country. The process and cost of such rehabilitation has been monitored over the past year as 1.6 hectares of old landfill are converted into a Materials Recovery Facility for the existing container deposit recycling system. This paper brings together all of the experience and knowledge gained with working these landfills over the past 20 years.

Keywords: atoll; landfill; leachate management; Nature Based Solution; landfill design.

1. Introduction

The Republic of Kiribati is a Small Island State in the central Pacific Ocean, straddling the Equator from 4º N to 11ºS; the nation consists of three island groups and population is growing at 2.2% per annum with around 124,000 people today, and the median age is 23 years old. Per capita GDP is about US$1,700, although there are likely great disparities between those in the urban area of the capital and those in remote islands. South Tarawa is the capital of Kiribati, consisting of a chain of islands linked by causeways on Tarawa Atoll; urban South Tarawa population is c. 65,000, with an average population density of 3,900/km^2; the most densely populated island of Betio having a density of approximately 10,500 persons/km^2. The islands are at most only a few hundred metres wide, and so, in typical atoll fashion, land is scarce. There are three main centres in the capital of Betio, Bairiki, and Bikenibeu. Each has a landfill site, with the site for Bairiki being on the adjoining island of Nanikaai.

On South Tarawa, Betio Red Beach landfill is the oldest, and was for many years an uncontained lagoon-side tipping site (see figure 4); in the mid 1990's a wall, comprising a wide sand bund with sandbags covering the outside of the seawall, was built around it. In 2004-5 two more landfills were built, one to serve Bairiki at Nanikaai, and another at Bikenibeu. All three landfills are situated on lagoon-side tidal sand flats; in all three the effective floor of the landfill is around a metre below mean sea level. The 2004 landfills consisted of a trapezoidal section wall of 3 to 4m height, typically 3m across the top and 6m at the base, made with sand dug from the sand flat, and covered by sandbags filled with a sand and cement mix. The floor of the landfill was 'stabilised' by mixing bags of cement with the lagoon sand, using a backhoe as the mixer; the mixing rate was reported to be one bag of cement per square metre of base area. Figure 1 shows a sectional schematic view of the construction.

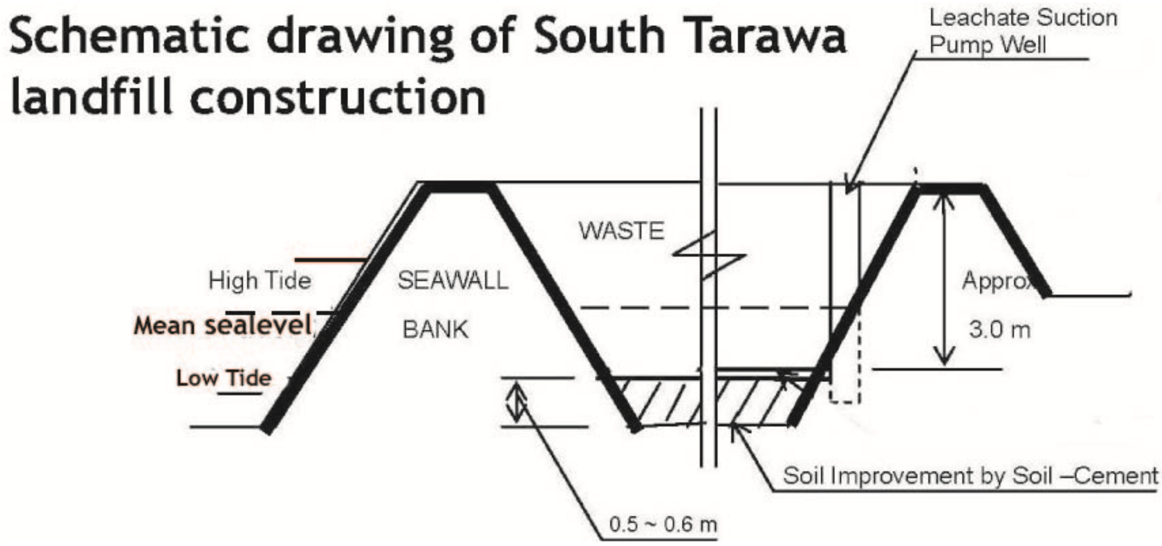

Figure 1 Cross-sectional drawing of South Tarawa landfill construction.

On completion of the two new landfills in 2004, it was found that the landfill retained a constant 1.2m or so of water, but it was unclear whether this water was from rain or sea. As the tide went out, the water level in the landfill remained apparently stationary and above the tide; the water level was determined after some study to be at mean sea level. Nanikai Landfill commenced operations in mid 2004, and started to receive waste which was tipped into the pool of water until the level of waste grew above the water. Bikenibeu did not receive an Environment Licence, partly due to uncertainty about the water level problem, until this issue was resolved in 2012 as related below[1]. Study was required in order to gain insight into the hydraulic relationship between the water in the lagoon, and the water in the landfill. Understanding this relationship greatly assisted in understanding how any leachate that collects in the landfill might interact with surrounding water bodies.

In addition to studying the water interaction, a water testing regime was instituted in 2011, with tests at all three landfill sites. At this time, Bikenibeu landfill was still unused and had no waste inside, and this provides an excellent baseline to work from, particularly with regard to monitoring Nanikaai, which is of identical construction but which had already been accepting waste for seven year at the time of the tests. Due to limited capacity for water

[1] And as related in the paper presented at APLAS 2012:Landfill Construction and Leachate Management for Atolls

testing in Kiribati, all the samples had to go to New Zealand for testing. The tests comprised a suite of heavy metals and other indicators, and the 2011 - 2013 tests were done under the guidance and assistance of the New Zealand National Institute for Water and Atmosphere (NIWA) and funded by the New Zealand Ministry of Foreign Affairs and Trade (MFAT). The water tests revealed that pollution from the active landfills - and subsequently Bikenibeu landfill once it opened - was considerably less than might be expected given that the landfills had no liners, the initial leachate pumps failed soon after installation and were not repaired, and the wall construction method was crude, with a non-structural concrete 'skin' of sand and cement-filled sandbags covering the sand bund wall. Discussions at APLAS 2012 with Professor J-L Vasel from Belgium raised the likely solution that the calcium carbonate atoll sand, which is entirely from biological sources, was acting as a leachate treatment system, providing an excellent example of a Nature-Based Solution to the very challenging problem of landfill leachate management on atolls (the installed leachate treatment was simply to pump the leachate into a local sewer which discharged direct onto the reef). This paper seeks to update the information provided in 2012, and also cover the technical challenges that have been met to fill such a landfill, and then rehabilitate it to turn the landfill into a useable piece of land in a place where land is so scarce, especially for commercial uses.

2. Interaction of Landfill Water With Surrounding Water Bodies

It is important to understand the hydrodynamics of the atoll landfills in order to appreciate the results of the water testing regime. The work in 2011 produced the following findings:

a) The area enclosed by the landfill seawall will fill with brackish water to mean sea level;

b) The water inside the landfill will show the highs and lows of the diurnal tides, but at about two orders of magnitude lower than the tidal range;

c) The water in the landfill will show spring and neap tide characteristics, but the matching peaks in the landfill will lag the tide by 64 hours;

d) A coastal fresh water well into the water lens, but near the sea, will exhibit similar patterns, except that the range is around one order of magnitude less than the tide, and the lag from the tide is around 50 hours;

e) As the landfill is built into the lagoon coastal sand-flat, there is no fresh water lens under the landfill for leachate to contaminate.

Figure 2 shows points a) to d) in a graphic format. Three sets of data are represented as three traces on the graph. The lines show relative differences, not absolute differences, as the two data loggers used to measure depths – the blue trace from inside the landfill, and the pink trace from a well close by - were at different depths below the surface of their respective waters, and are scaled on the left side of the graph. The sea level – green trace - is scaled on the right side, which scale is ten times the data logger scale. The sea level data trace is from the tide gauge at Betio, about 20 km away. The sudden rise in the blue trace is caused by a high rainfall event that raised the water level in the landfill.

What we see clearly is that there is an interaction between the landfill water and the surrounding sea. Similarly, as is well known, there is an interaction between the fresh water lens (fresh water sitting on top of salty water in the sand of the atoll island) and the sea. This interaction largely takes place through the sand floor of the landfill; if the walls are impermeable, then all the interaction will take place through the landfill floor. This is important to note as the pathway of the landfill leachate, through the sand to the

surrounding sea, is much longer through the floor than through the walls, and that pathway is entirely through sand made of calcium carbonate sea-shells from a variety of marine life.

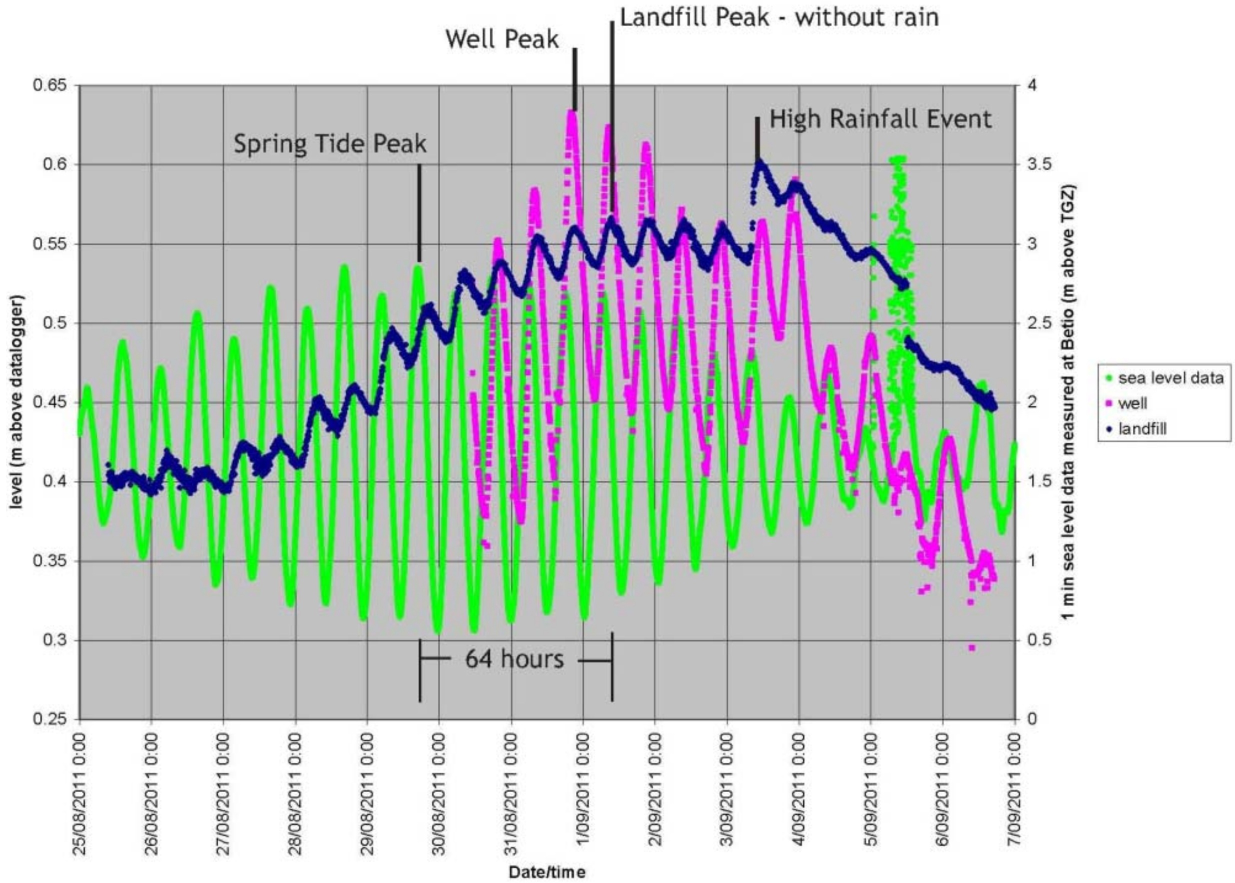

Figure 2 Relative movement of sea, well and landfill water levels at Bikenibeu landfill.

3. Water Monitoring 2011 - 2024

Water quality sampling was undertaken at the three landfill sites (Bikenibeu, Nanikai, Betio) on five occasions during the period December 2011 to November 2013, and then again in late 2022 and January 2024. The 2011 - 2013 tests were conducted by NIWA with funding support from the New Zealand Government, and at the request of the Kiribati Solid Waste Management Programme (KSWMP) also funded by New Zealand. The second set a decade later were at the instigation of Phase III of the KSWMP, recognising the importance of conducting ongoing monitoring. All tests went to New Zealand and involved tests for twelve metals plus phosphorous and nitrogen parameters, as advised by NIWA. Samples of water were also taken from inside the landfills, where possible. The results from these test show that the landfill walls do allow some contaminants to leach through to the surrounding lagoon or near-shore ocean waters. However, the level of exceedance of water quality guidelines is low, with generally less than a 5 to 10-fold dilution required to achieve the guideline concentration. These measurements indicate any adverse effects would be localised and generally limited to 10m to 20m distance from the landfill walls. The concentrations of copper was the most common contaminant which exceeded guidelines at each of the landfills. Concentrations of heavy metals, such as mercury and cadmium, which

might seriously affect food-chains were not present at levels of concern[2].

By 2024 the original landfill walls are in various states of repair, and at Bikenibeu the situation is serious, with cracks having been apparent for several years, although some small-scale patching efforts have been made to slow down degradation. In January and February 2024, after sustained - and unusual - west and north-westerly winds during the previous three months, the Bikenibeu landfill wall suffered major damage in three parts, one section very severe. At the time of this wall damage occurring, a new round of tests were conducted to try and determine the impact of this damage, and see if leakage from Bikenibeu was markedly increased. Of particular interest is that Bikenibeu landfill is not yet half full, and still contains a large body of water where the waste dumped has not yet filled the cell to above mean sea level. Figure 3 shows the damage to the landfill seawall, and it can be clearly seen that the concrete skin has no structural support, and is merely resting on the sand wall.

Figure 3 collapsed landfill sea wall at low tide, Bikenibeu landfill, Tarawa

It can be seen that the wall collapses inwards; the black hole - showing a void - at the centre left of the figure shows that there is nothing behind the concrete skin anymore. Two factors may be at work here: that the sea has infiltrated between the gaps in the sand bags that made up the concrete skin, and slowly washed the sand away, as no geo-textile or other membrane was placed under the bags during construction. Also, the passage of leachate through the wall, and the chemical reaction involved, may result in some loss of sand through the calcium carbonate going into solution. Photos taken during the wall construction clearly show that the concrete skin had no structural support whatsoever apart from that provided by the sand underneath. The wall was constructed twenty years ago, and has now reached the end of its life. In spite of this dismal condition of the wall - seen in Figure 3 - the January 2024 water test results at Bikenibeu were largely similar to the 2023 results, themselves not markedly different to the tests conducted a decade earlier.

4. Leachate Treatment By Calcium Carbonate

---

[2] Water Quality Monitoring Activity in South Tarawa, Kiribati: Monitoring of water and sediment quality of three landfill sites, NIWA 2013

The initial results from the water tests resulted in the hypothesis that the granula sand was acting as a physical filter medium, in the manner commonly used in some types of water filter. But at APLAS 2012 the authors were introduced to the work of Professor Vasel and colleagues and their work on using calcium carbonate as a leachate treatment system in the Montzen Landfill in Belgium[3]. Calcium carbonate proved to be an effective leachate chemical treatment medium, except that there were two significant practical difficulties encountered: the chemical reaction slowed down significantly below 15°C, whilst at temperatures above 25°C treatment was of the order of 100%; the second problem was that of maintaining a steady and consistent hydrostatic gradient across the calcium carbonate medium.

The situation in the Kiribati landfills is that both of these problems are solved by nature: the minimum temperatures normally encountered are 26°C, and the climate is very moderate equatorial as the sea surrounds these tiny islands, with daytime temperatures in the mid 30°C. Thus the temperature problem is not a problem in Kiribati. The second issue is dealt with by the tidal movement being such that for six hours the landfill water is moving out towards the lagoon, and then for six hours the sea - lagoon water - is moving back into the landfill. The velocity of water across the sand wall might be somewhere in the range of 0.2m to 2m per hour, but has not been measured; however, most of the interaction between inside and outside water happens through the base of the landfill, where the pathway is many metres long. Note in this respect how the water level inside the landfill seeks an equilibrium with the outside, only significantly disrupted through rainfall.

A third factor in favour of this Nature-Based Solution to leachate treatment in Kiribati is that the sand in Tarawa has a major component formed from both algae, such as the red calcifying algae *Jania*[4] and protozoan *foraminifera* organisms, as well as corals, and much of the sand is of a very fine nature, giving an excellent surface area to volume ratio for the sand particles in this instance. The papers and verbal information provided by Professor Vasel at APLAS 2012 were essential in providing the missing piece of the puzzle as to why these crudely built landfills were not causing the level of pollution that one might - reasonably - expect. The challenge now is to use all this information and experience to design new landfill for atolls that integrates the calcium carbonate leachate treatment system into the design, and not simply have it as a by-product of a crude and inexpensive landfill in an LDC.

5. Rehabilitation of Existing Landfill

Two of South Tarawa's three landfills are now full, Betio and Nanikaai. At the third, Bikenibeu, the wall is in a perilous state. A Materials Recovery Facility (MRF) was set up in 2004 on a government-owned site of reclaimed land next to the Port of Betio, where aluminium cans, PET bottles, used lead-acid batteries, e-waste and scrap metals have been processed since 2005. In 2021 Cabinet ordered the recycling operations to vacate the site to allow the Kiribati Ports Authority to expand as the Port itself had become severely constrained. In order to move the MRF and its operations, a new site was required, ideally also close to the Port. Land availability in Tarawa is very tightly constrained, and as noted, Betio Island where the port is located has a population density of over 10,500 persons/km^2. The existing Betio landfill covers an area of 2.27 hectares, and was enclosed with a wall in 1997 after being an open beach dump for many years prior to that, see figure 4 below. With

[3] J.-L. Vasel and H. Jupsin 2004
[4] pers. comm. Austin Bowden-Kirby, during a tidal reef-flat inspection of fauna and flora, September 2024

the landfill at capacity, but still taking waste, a plan was developed to rehabilitate a significant portion of the landfill, set the finished height at the top of the wall, and move the MRF to that location, about 500m by road from the port. Over the period May 2023 to September 2024, 1.6 hectares of the old site has been flattened, compacted, and capped with a reef-mud (lagoon sand) cap. This work has been conducted almost entirely using a Hyundai 740-9 12-tonne wheel loader, in the absence of any other heavy machine available. This machine also conducts ongoing compaction and maintenance work on all three landfills. The machine was donated to the Kiribati Ministry of Environment, Lands and Agricultural Development (MELAD) by MFAT, is operated by the KSWMP, and is fitted with sold rubber tyres so that it can travel by road between landfills, whilst also being immune from tyre damage when working on the landfills. Whilst it is not ideal for this work, it is a multi-purpose heavy machine that can provide a surprisingly good result in a resource-poor place like Kiribati.

Figure 4 Betio landfill c. 1990 prior to construction of a containment wall in 1997

As part of the rehabilitation process, the existing waste, which had had only intermittent heavy machine attention over the last 30 years, was levelled, and spread in thin layers using the bucket of the loader, shaking it out as it drove over the waste. Ultimately, this becomes a matter of how much machine time and diesel one is prepared to spend. An agreement was made with the Kiribati Ports Authority (KPA) to allocate some of the rehabilitated landfill area for shipping container parking to relieve pressure at the Port, and as a contribution to this, the KPA refuelled the loader from their own diesel bowser. Analysis of the costs over time from the machine logbook indicates and all-up cost of around A$30 per hour, including driver ($10/hr) and fuel and maintenance. It is of note that the machine was new at the start of this work, and so maintenance costs have been nearly all scheduled maintenance consumables. About 500 hours were spent on the landfill rehabilitation work only, at a cost of around A$15,000, and whilst there have been some other costs where for example a dump truck was employed to move waste for a few days, and an excavator to clean up some areas, the total cost for just the landfill rehabilitation works would not exceed A$25,000 (US$17,000).

In addition, the works involved creating more space at the active landfill area by removing old waste and spreading and compacting this over the rehabilitated area, which also meant that the land finished height could be lifted as well as levelled. In this way, the highest land on Betio Island has been created, at about 4m above 'seaframe datum'. The highest point on South Tarawa, at Eita village, is said to be 3m above mean sea level. The

levelled and compacted waste was then covered with a nominal 300mm of reef-mud which is obtained from an SOE dredge operation that mines the lagoon at Betio for construction materials. This has required around 4,500m^3 of sand, the cost of which has varied over time as prices have changed, but started at A$55/m^3 and is now A$75/m^3. As there is no weighbridge or other measuring equipment available at the dredge yard area, volumes are nominal. Difficulty has frequently been experienced to obtain dump trucks of any size to regularly transport the sand the 2km to the landfill site.

Part of the construction involves building a new Materials Recovery Facility shed of 300m^2. To do this, the waste in the landfill was dug out under the foundation area until the original beach sand was found at a depth of about 4m. This area was then backfilled using reef-mud, sand and hard rubble construction waste as it became available. The backfill process required about 2,000m^3 of backfill, and took about six months, using much of the construction rubble that was generated on the island as it became available. In some instances, because there is such a lack of availability of heavy equipment, the KSWMP could make 'deals' with those demolishing old concrete buildings to make way for new construction so that the KSWMP wheel loader was made available at the demolition site to load a dump truck to bring the rubble to the backfill area. As of October 2024 the new shed is on site as a kit-set from Australia, but the concrete pad is only just under construction. The new shed will be 15m x 20m and contain baling presses for cans, bottles and scrap metals, handling areas and equipment for used lead-acid batteries, a workshop / maintenance area, and shelving for second-hand car parts recovered from the ELV vehicles that will be baled on site.

6. Waste to Landfill Monitoring Methods

Kiribati has no operational weighbridge. There is no direct means to measure the amount of waste going to landfill. In the 2012 - 2013 period estimates of waste to landfill were made by using the top of the landfill walls as a benchmark, and estimating the remaining air space every six months. The landfills at Bikenibeu and Nanikai are rectangular and of similar construction, with a concrete top plate to the walls of 2m wide and each slab 6m long; this allowed the landfill to be easily broken into a grid of 6m x 6m squares, and the height of the waste below the wall top benchmark estimated for each square. This was done both simply by visual observation after compaction, and also at one time using the Lands Department surveyors, and the results broadly agreed. By this method the volume change per year could be estimated, and then, by applying various landfill density factors, estimates of the tonnage of waste to each landfill could be made.

Since 2023, the KSWMP has had access to a drone, and trained two staff members to operate it. In August 2023, a visiting Australian surveyor was engaged to set up the benchmarks at each landfill, develop the flight plan, and conduct a training on operating the drone over the landfill. He then analysed the data and produced volume maps of each landfill. Six months later, in April 2024, the local staff replicated the surveys, and then sent the data files to Australia for analysis. A third survey should have been conducted by November. This now allows a local determination of volume change in the landfill, essential to determine the remaining life of landfill given the available space. Using various compaction - landfill density - factors, it is possible to derive ranges for the weight of waste going to each landfill. When these estimates are mapped against figures derived from waste generation surveys, some indication, albeit imprecise, can be determined regarding the

amount of waste that is captured by landfill compared to the estimated amount generated across South Tarawa. An additional input into these estimates is that the bulk of household waste is collected by the pay-as-you-throw Green Bag collection system, which collects bags across the island; sample tests indicate that the average weight of a Green Bag at collection is 5.3kg, and the system collects around 180,000 bags per year, or around 1,100 tonnes[5]. the two local urban Councils also collect waste, and much waste is transported to landfill by private haulers, largely commercial operators. Waste to landfill, assuming a density of 700kg/m³ (given likely low compaction rates using only the wheel loader) is of the order of 6,500 tonnes per year. The World Bank conducted a study in 2021 estimating that waste generation was 8,600 t/yr[6]. This would give a 75% recovery rate in South Tarawa, probably a realistic figure in general terms, mindful of the uncertainties in all the contributing measurements.

The use of the drone has greatly improved the monitoring capacity of the Ministry with regard to the landfill situation. Improvements in landfill operation have meant that the public - and Councils - have continuous access to landfill, whereas frequently before 2023 landfills would become blocked as no heavy machine was on hand to compact waste and keep internal access tracks open. For example, the World Bank study of 2021 estimated only 45% of waste generated was getting to landfill. Now the challenge is to build more landfill as the existing ones have filled up faster. It is of note that there was actually a perverse incentive existing previously, in that blocked up landfills did not accept more waste, and also saved money for Councils (who are nominal operators of the three landfills) by not requiring spending on the hire of heavy equipment, whilst central government did not need to spend money on building new landfills. Only now that a dedicated Programme - KSWMP - is tasked with improving the situation does the real magnitude of the effort required become apparent.

7. New Landfill Construction

The challenge now is to build new landfills, but with all the knowledge gained over the past twenty years of operating the current ones. Both Nanikaai and Betio landfills are full (Nanikaai is about 2,000m³ above the walls at the time of writing, although the waste is flattened and compacted into a domed shape) whilst at Bikenibeu the landfill has ten years or so of life, but the walls are collapsing. Using the knowledge gained from studying the landfill water interaction with the surrounding sea, and the chemical treatment of the leachate that the calcium carbonate sand is providing, it should be able to integrate these factors with existing civil engineering knowledge about building seawalls and revetments into lagoon sand flats, to provide a reasonable cost landfill per metre of seawall, or similar metrics. The KSWMP is currently engaged with the UNEP GEF ISLANDS project to tender out a consultancy to conduct the design work to do just this. Once a viable design is in place, budgets can be developed to build more landfill, and funding sought. Both Nanikaai and Betio can have extensions built onto the existing landfills that will allow continued use of the

[5] This rate has increased significantly since July 2024 as two trucks are now operating, projections are for around 300,000 bags per year, around 1,600 tonnes.

[6] World Bank, 2021, Kiribati Waste Characterization and situation Analysis Report: Analysis of Waste Generation and Disposal Data

existing landfill gatehouses. As the landfill is government-owned land, the issue of land ownership does not arise if extensions are built at the current sites.

8. Conclusion

These landfills are much more than just places to put the rubbish. Well managed and compacted landfill has the potential to produce useful land that is higher than the surrounding land on each island, land that has use for commercial purposes, such as construction yards, recreation fields, container parking, or various other non-residential uses on islands where space is extremely constrained and land is becoming very valuable as no space remains. The example above of using the old landfill as the new Materials Recovery facility, which will act to divert waste from landfill, and create economic opportunity through jobs, exports, and skills training, is a vital part of the equation. The tools and experience developed over the last decade are essential for creating better managed landfill, that will produce useful land, and not be seen as simply a drain on the public purse. The monitoring methods detailed above have shown that even in remote places where the technical capacity does not exist to conduct detailed water tests, waste to landfill weights, or with survey skills to hand, that local partners can still conduct the on-ground work whilst utilising off-shore technical skills - such as testing and surveying analysis - that are only needed annually or so. Landfills have tended to be seen as dirty and undesirable - which in many ways they are - and in a perfect world would not be needed. But in the atoll nations - such as Kiribati - landfills can have an important role to play to help the country improve and move into an uncertain future.

Acknowledgements

Authors would like to acknowledge the support of the Ministry of Foreign Affairs and Trade of New Zealand for their funding support to the Kiribati Solid Waste Programme Phase III; Also: Clive Carpenter, Joanna Ellis, GWP Ltd, UK; Tony Falkland, Island Hydrology Services, Australia; Mike Crump, Water Quality Laboratory Manager, National Institute of Water and Atmospheric Research Ltd., New Zealand; Matt Holdsworth, Kiribati Water Quality Monitoring Project, ESIR New Zealand; Aaron Hick, Drone Surveyor, Australia; and Professor Vasel for his insights at APLAS 2012 in Bali.

7. References

Kiribati Solid Waste Management Programme, 2022 - 2024, Quarterly Technical Reports

Vasel, J-P, El Massoui, M, and Praet, E, 2003 Modified Infiltration-Percolation System for Nitrifying Leachates from Sanitary Landfill: Validation on a Semi-Industrial Installation

Vasel, J-P, Huspin, J, 2004 Nitrogen Removal During Leachate Treatment: Comparison of Simple and Sophisticated Systems. Fondation Universitaire Luxembourgeoise, Arlon, Belgium

United Nations High Commissioner for Refugees, 1992, Water Manual for Refugee Situations, Program and Technical Support Section, Geneva.

Water Quality Monitoring Activity in South Tarawa, Kiribati: Monitoring of water and sediment quality of three landfill sites, NIWA 2013

World Bank, 2021, Kiribati Waste Characterization and situation Analysis Report: Analysis of Waste Generation and Disposal Data