Landfill Construction and Leachate Management for Low-lying Coral Atolls

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Abstract

Construction of three landfills built into the tidal flats of an atoll nation are reviewed, with the intention to provide guidance to other atoll nations on landfill construction and management of leachates. Construction and management of landfills for solid waste in small atoll nations has historically proved to be challenging. Some of these small island states have developed significant urban areas, producing large quantities of solid waste where dry land is unavailable for landfills. South Tarawa, in the atoll nation of Kiribati, has three operational landfills in different stages of development; these serve 50,000 people on a set of connected islands with population densities up to 10,000/km². The landfills have been built into lagoon tidal flats and initial study is provided here of the hydrological interaction of surrounding water bodies and the water inside the landfills. The resulting correlations in movements of the tide, adjoining wells, rainfall, and water bodies inside the newest landfill provide some indications for improved future landfill construction and leachate management in an atoll environment that may minimise local pollution, whilst being sufficiently low cost and low maintenance to be viable in a less developed nation with significant resource and municipal finance constraints. This subject lacks an existing body of literature and the results presented here show where further study is required; but there are some indications that an apparently crude construction and counter-intuitive approach to leachate management may provide useful information for the design, construction and operation of new landfills in atoll nations.

Keywords: coral atolls, landfill construction, landfill hydrology, leachate management.

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 around 105,000 and per capita GDP is about US$1,400. South Tarawa is the capital of Kiribati, consisting of a chain of islands linked by causeways on Tarawa Atoll; urban South Tarawa population is 50,000, with an average population density of 3,800/km²; the most densely populated island of Betio having a density of approximately 10,500 persons km². The islands are at most only a few hundred metres wide so, in typical atoll fashion, land is scarce. There are three main centres of Betio, Bairiki, and Bikenibeu. Each has a landfill site, with the site for Bairiki being on the island of Nanikai.

Landfill construction and management in the Pacific Islands has been notoriously difficult since the arrival of modern wastes. Whilst landfill construction on high islands has been improved significantly in the last decade through the application of the principals of the 'Fukushima Method', landfills in atoll nations are resistant to application of these principals largely for two reasons: lack of space to make landfills inland, and the flat landscape has a lack of hydraulic gradient to assist in leachate collection and processing. Landfills on atolls are primarily seen as an opportunity to make more land: as a consequence, urban landfills in the atoll nations of the Pacific are situated in coastal areas with their bases below sea level, and no leachate management is even possible in this situation without sea containment, a pumping system, and associated running cost and maintenance problems. As a result, there

has not been a conventionally managed sanitary landfill amongst the Pacific atoll nations. The authors were unable to find any existing studies on the subject presented here[a].

On South Tarawa, Betio Red Beach landfill is the oldest, and was for many years an uncontained lagoon-side tipping site; in the mid 1990's a wall, comprising a wide sand bund wall with sandbags covering the outside of the seawall, was built around it. In 2004 two more landfills were built, one to serve Bairiki at Nanikai, 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 below mean sea level, and each was provided with a leachate pump in a sump intended to drain the landfills, each of which held significant water. The leachate pumps were connected to the existing sewerage systems in each location that expelled leachate untreated into the ocean at the edge of the ocean-side reef flats. The 2004 landfills consisted of a trapezoidal section wall of 3m 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. Fig. 2 shows a sectional schematic view.

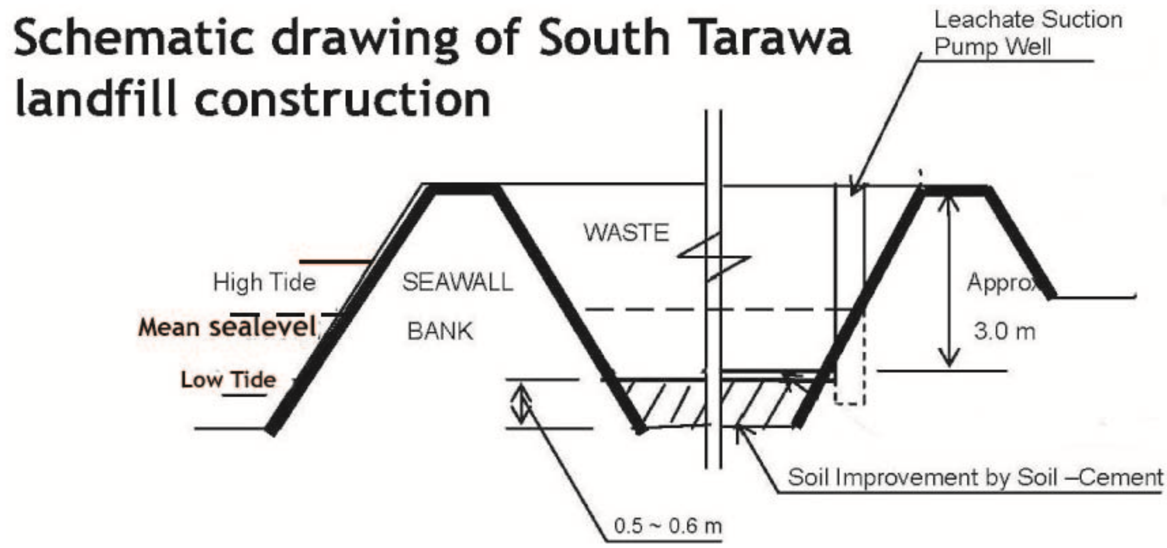

Figure 1: Cross-sectional drawing of Bikenibeu landfill construction.

On completion of the first of the two new landfills at Nanikai, it was found that the landfill retained a constant metre 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. Due to the constant level of water, the leachate pump, which was designed to operate through float switches in short bursts and pump the sump out periodically, ran continuously and consequently soon failed. 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 never received an Environment Licence, partly due to uncertainty about the water level problem, and was never opened. 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 should assist in understanding how any leachate that collects in the landfill might interact with surrounding water bodies. The research and results presented here were conducted by the authors during 2011 to ensure that the landfill was fit to be licensed for use, and obtaining a licence to operate. The authors are not specialists in water movement, but are responsible to ensure that the integrity of the landfill is sufficient to allow it to operate effectively and improve the local solid waste management situation without causing adverse impacts.

[a] The Secretariat of the Pacific Environment Programme (SPREP) currently has no guidelines regarding landfills on atolls, but has two volumes covering 'high' islands.

2. Methodology

The key questions are: a) where does the water inside the landfill come from?; b) is it that the water in the landfill is being fed from the lagoon, and does it fluctuate at all with the tide (a range of up to 2.3m on a spring tide)?; c) if the water level was largely influenced by rainfall, why did the water level not significantly decrease during the 10 month drought from May 2010 to March 2011? Understanding how the water moved is essential to determining requirements for the leachate management system.

The inside wall of the landfills is composed of twenty layers of cemented sandbags providing a simple visual marker for the water level. Photographs taken over the 2005 – 2011 period were compared, and it was noted that the water level was remarkably stable with only a difference of around 1 bag (150mm) discernable. The water level was then closely observed during the 6 hour cycle of a spring tide, but no clear movement was observed, even though at high and low tide the sea level was above and below the water level inside the landfill. During this observation period, it was noted that a weekly difference – between a spring and a neap tide – was observable. It was already known that ground water levels on Tarawa move with the tidal cycle, and this provided some insight into the issue.

Three water bodies were then studied: the lagoon water, the water in the Bikenibeu landfill, and the local ground freshwater lens. Relative water level movement between each of these water bodies was measured by borrowing two water level data loggers, one placed inside the landfill leachate pump sump, the second inside a household well only 10m from the south east corner of the landfill, and 10m inland from the high tide mark. The information from the data loggers was then compared with the tidal data from the tidal gauge at Betio Island, 21 km to the west; the tidal time lag between Bikenibeu and Betio is estimated at 30 minutes. Rainfall data for the period was also obtained, and included in the analysis. The data loggers were only available for a short time, being borrowed from a visiting consultant on another project, but sufficient data was collected to confirm the visual observations. The data logger in the landfill pump sump was operated for 12 days, and the one in the well was only available for eight days which coincided with the last eight days of the same period. The results from the data loggers were compensated for atmospheric pressure, and the influence of rainfall was also included in the analysis.

Water testing was conducted at this - unused – landfill, and also at the two operational landfills. Nanikai Landfill is of a similar construction to Bikenibeu; Betio Landfill is of a cruder construction than the others, its wall having only an outer covering of cemented sandbags, however, the sand wall thickness is considerably greater. Water samples were collected from surface water within the landfills and at four sites in the lagoon immediately adjacent to the landfill walls. Each site had one or two reference samples taken from a more distant site in the lagoon to establish the background water quality. All samples were analysed for nutrients (nitrogen and phosphorus) and 12 metals typically occurring in leachates. The metals included those naturally elevated in landfill leachates, such as iron and manganese, and those highly toxic to aquatic species (e.g., cadmium and copper).

3. Results

The three sets of data are represented as three traces on the graph in Fig. 3. The lines show relative differences, not absolute differences, as the two data loggers – the blue and pink traces - 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. New moon was 29th August, with the peak spring tide of this cycle being 2.25m, expected at Bikenibeu at 05.30 that day; first quarter moon was 5th September, with the neap cycle minimum tidal range of 0.43m straddling 5th- 6th September. Heavy rain (25mm) occurred on the morning of 3rd September, as is seen by the rapid rise of the blue track on the morning of that day; rainfall data comes from the Betio Weather Station,

but in fact the rain was still falling in Bikenibeu after finishing in Betio that morning[b]. Note that some anomalous data shows up: the tide gauge at Betio shows anomalous readings around 4th to 5th September. The gap in the landfill water (blue trace) on September 5th was caused by lifting the data logger, but it did not go back to the same depth. The disruptions to the well water trace on 5th and 6th September were caused by well usage.

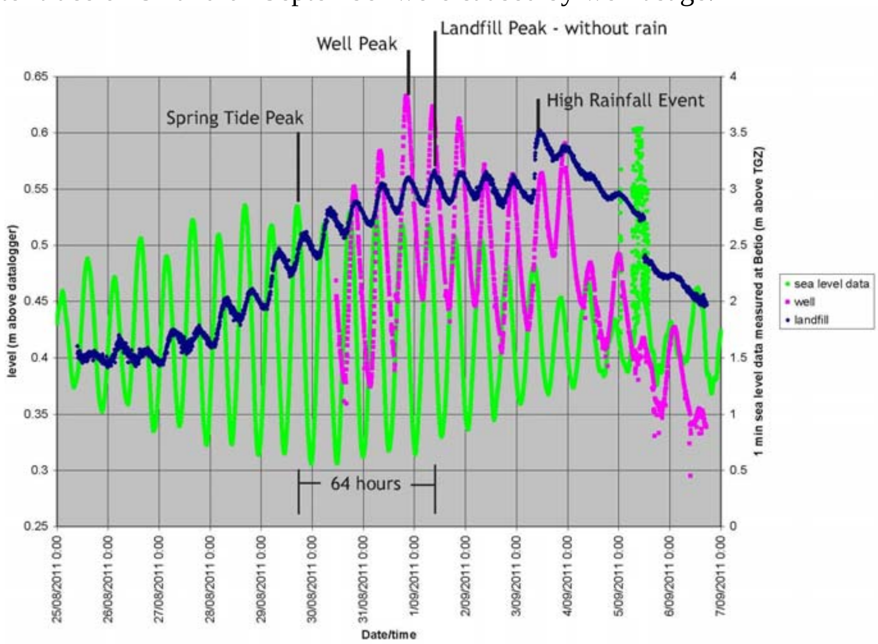

Figure 2: Relative movement of sea, well and landfill water levels at Bikenibeu landfill.

The peak tide reading was at 1700 on the 29th August, and the peak landfill water level (discounting the impact of the heavy rainfall of the 3rd) was 09.30 on 1st September. Allowing for difference in tide times from Betio to Bikenibeu, this shows a lag of 64 hours between the two peaks. The well water peaked at 20.30 on 31st August, and this shows a lag between peaks of 51 hours. Fig. 4 shows the daily rainfall against the data logger information, as recorded each day at 9 am at Betio; it can be seen how low levels of rainfall increases the absolute level of water in the landfill, but not the cycle. However, the heavy rain of the morning of 3rd September disrupts the cycle for several days, similarly, but to a lesser extent, this is seen in the well water trace. The highest spring tide was on 29th August, the range being 2.24m; after the 29th the tide amplitude dampens. The landfill range following this high tide was 22mm (0.022m). Sea level change leads groundwater level, which in turn leads landfill water level changes. On 30th August (no rain) sea level high led the well level high by about 2 hours, which led the landfill level high by about 2 hours i.e. there is a 4 hour lag between sea level high (at Betio) and landfill high. Allowing for the tide lag at Bikenibeu, these figures become 1.5 and 3.5 hours respectively.

The following points stand out:

a) water levels in the landfill vary by about 20 – 40mm (without rainfall added), with time taken for maxima and minima change about 6 hours (similar to the tide);
b) water levels in the well vary by about 200 – 240mm (normally about 200mm) over a similar period between maxima and minima;
c) the ratio varies, but is around five to eight times the movement of the well water compared to the landfill water level;
d) the peak water levels in both landfill and ground (discounting rainfall) are days after the peak tide, an unexpected result, but clearly shown from both data loggers.

Water levels in both landfill and well are affected by rainfall i.e. the pattern diverges from the modulated tidal changes, for example after the rainfall on 3rd and 6th September. The rainfall effect is seen in detail after heavy rain on 3rd September, when 25mm fell; the tide

[b] Author's personal observation

was approaching mid spring-neap, and a variation of about 30mm would be expected in landfill water level, based on days when there was no rain, but there was 56mm variation – roughly equivalent to the expected tidal variation plus the rainfall. This implies that the direct rainfall on the landfill is staying in the landfill for some time, indicating that the walls of the landfill do retard the rainfall flow out to the lagoon somewhat (assuming that the evaporation losses would have been a maximum of 2-3mm).

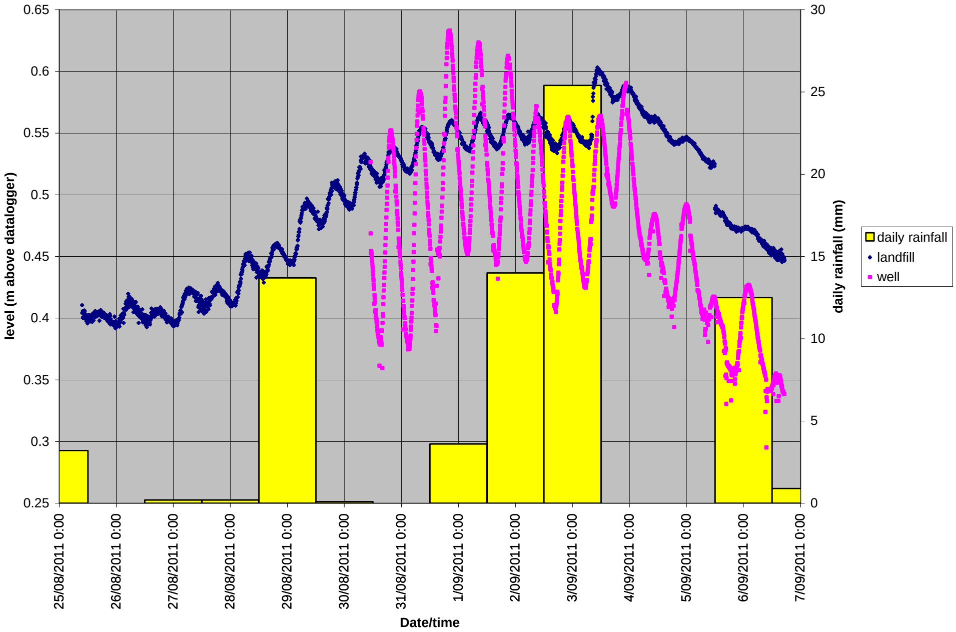

Figure 3: Impact of rainfall on landfill and well water levels.

The water quality tests[c] from both inside and outside all three landfills showed that both nutrients and some metals (primarily iron and manganese) were highly elevated in water from inside the two operational landfills (Betio & Nanikai), yet trace levels of both nutrients and metals were detected at only one sampling site adjacent to each of these landfills when compared with the local reference site – indicating a slight seepage to the lagoon at those points, and these seepages are actually visible. Where the walls are sound, results indicate the landfill is containing the leachates effectively. Sampling conducted 6 months later in March 2012 provided results consistent with these; the next round of testing will be in September 2012, and sediment testing is confirming these results.

4. Discussion

The dataset obtained is for a comparatively short period of time and should ideally comprise a far longer period of time, covering at least one month of tidal cycle; this qualification is important when considering any discussion and possible conclusions. The long lags between peak tide figures and peak ground and landfill water figures – several days – have surprised water specialists familiar with this environment and need closer investigation. The water level in the landfill varies diurnally, as does the groundwater level in the well, indicating that both are exhibiting a pressure response due to the tidal changes – one through the pressure response transmitted through the landfill walls and base, and the other through the fresh water lens of the island. The relative difference between the landfill water level change and the tide change over the same cycle is about 100 times. This indicates that there is a dampening of the tidally induced water level changes inside the landfill. The difference between tidal range and well water range is of the order of a factor of five to eight. Water specialists consulted by the authors were unable to agree on an explanation for this.

[c] Water quality tests were conducted by the National Institute of Water and Atmospheric Research Ltd., New Zealand; detailed data is available but space constraints do not allow detailed representation here.

For each six hour tidal cycle, the water level peak in the landfill lags the peak in the groundwater level typically by around 2 hours, i.e. the pressure response from the sea through the water lens to the well is quicker than through the walls and base of the landfill. This is true even around 31st August when there was no rain, so this lag is not explained by recharge differences. The velocity of water across the sand wall might be somewhere in the range of 0.2m to 2m per hour, but was not measured. So over a tidal cycle of 6 hours, with a minimum wall thickness of 4 m for the water to cross, the sea water might not actually cross the wall into the landfill before the tide goes out again and the hydraulic gradient reverses. Sand has long been used as an effective filter medium for purifying water, and slow sand filters are frequently used as a low-tech option for water purification[d]. However, these filters as used require a biological 'schmutzdecke' which requires ongoing regular management and does not, as such occur in these landfills in the manner used in a slow sand water filter.

5. Conclusions

These investigations and results are of a simple and rudimentary nature. The original design called for – and installed – leachate pumps. The leachate was pumped into the existing sewer systems and dumped untreated onto the ocean-side reef. As the landfills naturally filled with water until reaching a hydrostatic equilibrium which matched the level of the landfill floor apparently relative to mean sea level, the pumps, designed to pump small amounts of leachate trickling into a sump, failed in time. The cost of running a pump 24 hours per day until the landfill waste level exceeds the water level (several years of filling) is also prohibitive, and the pump will not stand it, requiring regular replacement as the effort is in effect simply pumping out the seawater that will flow into the landfill, an exercise of a Sisyphean nature. The operation and maintenance of a leachate pump over the expected landfill lifetime (perhaps 20 years) in such circumstances is a very significant problem in a country where maintenance of any equipment is an ongoing challenge.

It is very clear that further study is essential to provide a greater understanding of the water movement in this circumstance, in order to help with future landfill design and construction in an atoll environment. The results indicate that initial construction will determine how leachate is to be managed; a hypothesis could be developed that a well constructed landfill could allow water movement across its wall, but be shown to contain the pollutants in the leachate effectively within the landfill. There is insufficient evidence presented here to take that as a solid conclusion at this time. A sealed landfill base and walls that do not allow water movement will almost certainly result in flooding during wet periods (such as recently experienced in Tarawa) and make day to day operations extremely challenging. If leachate pumps are not required, operational costs would be considerably lower. The three landfills in South Tarawa, given their different ages and stages of operation, provide an excellent opportunity to increase the level of understanding on this subject, and must continue to be carefully monitored if the existing low level of knowledge of this subject is to be improved.

6. Acknowledgements

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.

7. References

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

[d] UNHCR Water Manual for Refugee Situations, Program and Technical Support Section.