Performance of wastewater treatment eco-technologies applied in Fijian villages

Prepared for

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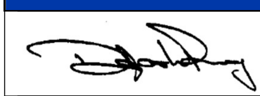
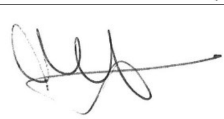
	Reviewed by:	Doug Ramsay (Manager, Pacific Rim)
	Formatting checked by:	Tracey Goodrick
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Executive summary

This report details the performance of a range of on-site and decentralised sanitation systems developed and tested in iTaukei villages in Fiji. Monitoring was undertaken as part of the WASH Koro project funded by the NZ Aid Programme of the Ministry of Foreign affairs and Trade.

The systems tested and key results were:

1. **Water-less dual chamber ventilated improved pit latrines,** known as ecoVIP2 toilets, are ventilated improved pit (VIP) toilets that promote an active decomposing humus ecology within the pit. (see KoroSan Guideline #6 for details). Soil and organic matter are added after each use of the toilet to absorb liquid, provide supplementary organic carbon and inoculate the faecal matter with microbes and invertebrates that promote its natural decomposition. Monitoring of ecoVIP2 toilets in a coastal and an inland village over 4-5 years showed little or no odour and an absence of nuisance insects such as flies or mosquito. Families using the ecoVIP2 toilets were readily able to maintain the systems after basic training and showed high levels of satisfaction. Decomposition of the pit contents was rapid with pile accumulation within the first of two pit chambers of 0.2-0.5 m yr^{-1}. The most intensively used ecoVIP toilet reached its maximum effective capacity within 4 years before requiring shifting of the toilet pedestal to the second (reserve) pit. This allows the first pit contents to aerobically degrade, markedly reducing the volume of faecal sludge remaining before reinstatement is again required. The ecoVIP2 pit latrines have shown themselves to operate very effectively over 4-5 years of use. They are cheaper to build and maintain than a water-flushed toilet and septic tank system, and do not require a piped water supply to function. Further monitoring through the pit resting period is warranted to assess the rate of sludge degradation, frequency of sludge removal required and potential safe reuse or disposal options for the stabilised sludge.

2. **Blackwater Septic Tanks** conforming to Australian and New Zealand Standards (AS/NZS 1547:2012) were monitored treating toilet wastewaters in two villages. These septic tanks (outlined in KoroSan Guideline #3) are larger than previously prescribed in Fiji and have effluent filters fitted to reduce discharge of suspended solids. Effluent quality assessed for 9 dual chamber septic tanks treating toilet blackwaters in 2 Fijian villages was generally poorer than reported for septic tanks elsewhere treating combined black and greywaters, but similar to that reported for blackwater septic tanks under subtropical conditions on the Gold Coast of Australia. The elevated contaminant levels found in blackwater septic tank discharges in the present study, particularly for ammonium-N, nitrogen, phosphorus and faecal indicator bacteria, show that they are of high strength and pose a significant risk to human and ecosystem health if allowed to discharge to surface waters. Such discharges also have a high potential to clog soak pits and soil infiltration systems and contaminate groundwaters. Rates of faecal solids decomposition in the blackwater septic tanks were rapid with low rates of sludge and scum accumulation. These larger tanks should function for extended periods (≥ 10 years) without the need for de-sludging under Fijian climatic conditions. This has significant advantages where the infrastructure for safe sludge removal is poorly developed.

3. **Land application systems** are designed to provide further treatment of septic tank effluents and reduce the contaminant load on subsequent soil infiltration systems. This reduces the potential for clogging of soak pits and soil infiltration systems and lessens consequent health and environmental risks. The systems tested in the present study involved pulsed dosing of sand filled trenches (as described in KoroSan Guideline #4). As the septic tank effluent soaks through the sand and associated biofilms, suspended solids, organic matter (BOD_5) and faecal bacteria (*E. coli*) are naturally filtered out, and microbes transform and reduce nitrogen loads. Further treatment occurs as the treated effluent soaks into natural soils. In the operational systems tested in sandy and clay soils in Fiji, effluent quality measured at the bottom of the sand-filled trenches usually exceeded Fijian national effluent standards (DoE 2007) for general discharge to receiving waters and frequently even met the stricter standards proposed for Significant Ecological Zones. Supplementary treatment of septic tank blackwater in land application systems such as these can provide an effective and sustainable method to manage blackwater septic tank discharges in Fiji villages.

4. **Constructed wetland** performance was assessed for the village-scale treatment system at Votua that had been in operation for 7 years. This system involves collection of blackwater septic tank effluents from around 50 homes via a gravity sewer system, followed by pumping to a multi-stage wetland system constructed inland of the village. The constructed wetland system is comprised of intermittently dosed vertical flow wetlands followed by horizontal flow wetlands operating in parallel. The initial vertical flow wetland was highly effective readily achieving Fijian National Liquid Waste Standards (DoE 2007) for direct discharge to a Significant Ecological Zone for TSS, BOD_5 TN, NH_4-N, and TP, and equivalent to general discharge standard for faecal indicator bacteria. Because of the high level of treatment provided in the vertical-flow wetland and substantial infiltration through its base ,the following horizontal-flow wetland stage proved largely unnecessary.

Field evaluation of the performance of on-site wastewater treatment systems is challenging and has rarely been undertaken in Pacific Islands or similar tropical settings. The results of this study show that the treatment options implemented were able to reliably manage toilet wastewaters in Fijian villages, achieving high levels of treatment. Information to support the proper implementation of these treatment systems is available in the KoroSan on-site sanitation guidelines for Fiji[1]. Application of these and other proven sanitation options in villages, settlements and peri-urban areas in Fiji that are currently reliant on unimproved pit toilets or substandard septic tanks, is likely to substantially improve the health and wellbeing of Fijians and reduce pollution of freshwaters and coastal areas.

[1] www.niwa.co.nz/korosan

1 Introduction

The capacity of village water supplies is gradually increasing across Fiji, with many villages transitioning from communal standpipes to piped supplies to individual households. This commonly leads to installation of flush toilets, kitchen sinks, bathroom facilities, and eventually the use of washing machines, creating a significant wastewater flow that needs management (Tanner et al. 2018). Without proper treatment and disposal, the increased discharge of wastewaters created by these changes can result in increased exposure of village communities to pathogenic microorganisms and associated health risks.

Small capacity septic tanks for toilet blackwater, exacerbated by leaking cistern seals, poor construction practices and a lack of periodic sludge removal, can result in rapid clogging of soakage pits and (where present) land application systems. Disposal into heavy clay soils, which are common beyond the narrow coastal fringe of coral sands, also causes problems. These fine-grained soils have low inherent infiltration capacity and are prone to clogging. This commonly results in failure of effluent disposal systems leading to emergence of effluent at the soil surface and contamination of nearby ground, drains and waterways, lagoons and beaches used for bathing and recreation by villagers and tourists.

In addition to common water-borne enteric diseases causing stomach upsets and diarrhoea, there have been reoccurring outbreaks of typhoid in villages around Fiji that have been strongly linked to contaminated water sources, inadequate sanitation facilities and poor hygiene practices (de Alwis et al. 2018, Jenkins et al. 2019, Prasad et al. 2018, Thompson et al. 2014, Watson et al. 2017). Improvements in sanitation practices have been recommended by The Expert Panel for the Reduction and Control of Typhoid Fever in Fiji (convened by the Fiji Ministry of Health in 2012) as a key action to reduce the high incidence of typhoid outbreaks in Fiji.

The Fijian Government has embedded the right to access clean and safe water and efficient sanitation services into the constitution, and has a National Development Plan target for both urban and rural populations of 100% access to safe drinking water and 50% access to improved sanitation systems by 2026, rising to 70% in 2036. (Fiji Government 2017).

In 2013 NIWA received funding from the New Zealand Aid Programme of the Ministry of Foreign Affairs and Trade for a multi-agency project into waste treatment technologies appropriate for Fijian villages. Known as the WASH Koro Project (Tanner et al. 2018), it aimed to mobilise community-led water supply, sanitation and hygiene improvements in Fijian villages by providing tools for villages to recognise and address their water supply, sanitation and hygiene needs. The project included consultation with villagers and provincial and national government agencies, capacity-building, environmental monitoring, site assessment and installation of household demonstration sanitation systems in Bavu and Namaqumaqua villages (Viti Levu, Fiji; Figure 1-1). A series of practical guidelines (KoroSan guidelines: Dakers et al. 2017a-e, Dakers et al. 2020a,b, Winstanley et al. 2017) were developed and training workshops run in consultation with the Water and Sewerage Department and the Ministry of Health to support wider application in Fiji (Tanner et al. 2015, Tanner et al. 2017a-c, Vishwa et al. 2017).

The Central Board of Health in Fiji provisionally approved the use of the KoroSan Onsite Household Sanitation Guidelines on 30 October 2017, subject to subsequent provision of a technical evaluation report.

The current report provides this technical evaluation report. It summarises the key design features of the village demonstration systems and describes the methods and results of monitoring undertaken to assess their operation and treatment performance. The on-site systems monitored include: household-scale dual chamber ventilated improved pit latrines (ecoVIP2), and blackwater septic tank and land application systems. The performance of a village-scale reticulated septic tank and constructed wetland treatment system previously established in Votua is also assessed. This system was implemented as part of the Wai

Votua Project (2006-2010; NIWA 2009) also funded by the New Zealand Aid Programme of the Ministry of Foreign Affairs and Trade.

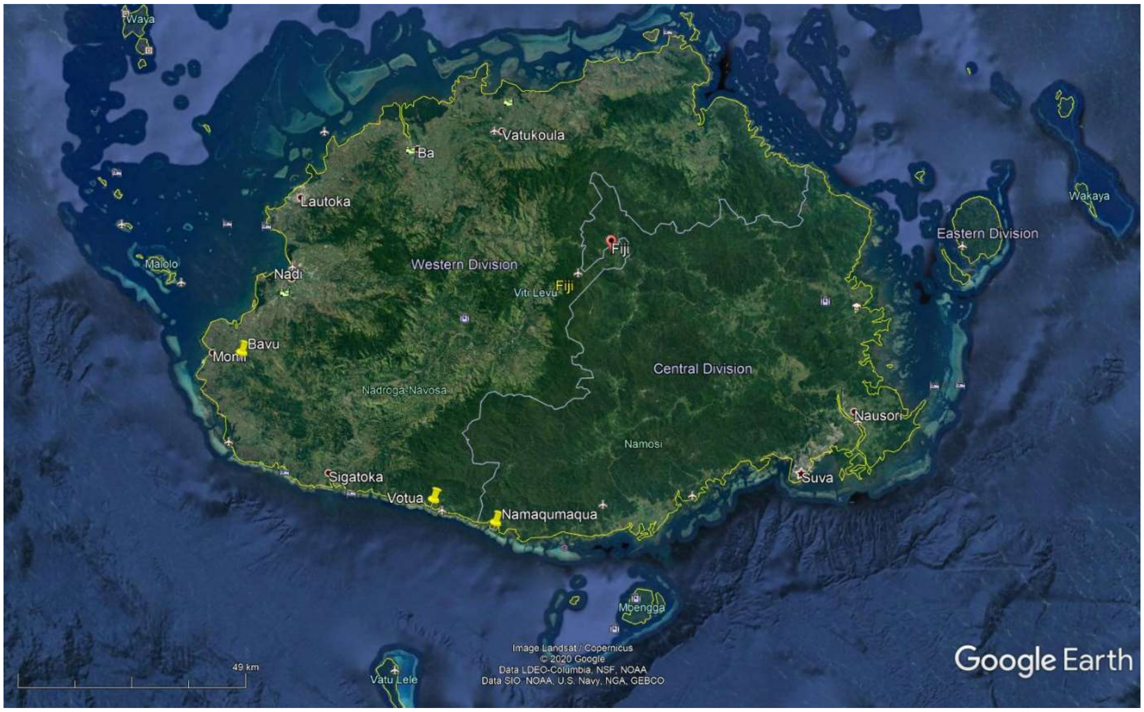


Figure 1-1: Village locations of the monitored treatment systems. Villages are on the "Coral Coast" in the southeast of the island of Viti Levu.

2 ecoVIP2 Improved ventilated pit latrine systems

2.1 ecoVIP2 system description

The Ventilated Improved Pit or VIP latrine was developed by Dyson Blair and Peter Morgan in the 1970s to improve the squat pit toilet commonly used in African villages (Morgan, 2009, 2014; Mara, 1996). VIP toilets and their variants are now widely used in developing countries around the world as a simple and effective low-cost toilet option. Their key features are ventilation of the pit to remove odours, a structurally sound pit and building, insect screening and reduced light entry so that any flies entering the pit are attracted up the vent towards the light. The ecoVIP2 is an adaption of the dual pit “fossa alterna” designed to enhance decomposition of the faecal sludge, significantly extend the time before desludging is required, and reduce associated health and environmental risks. (Dakers et al. 2017d). Organic leaf litter and soil is added by the users, either after each use or weekly, to provide extra carbon and introduce an inoculum of microbes, worms and insects to create an active humus ecology that promotes biological decomposition of the accumulated faecal matter.

Two ecoVIP2 systems were constructed for household use in Bavu and Namaqumaqua villages (Figure 1-1) as outlined in Dakers (2014a,b). They comprised a hurricane proof shed, a pleasant and easy to keep clean toilet pedestal, and a pair of well enclosed aerated pits. An example of this system is shown in Figure 2-1. There is one active pit and a reserve pit, which are designed to be used in sequence with the toilet pedestal able to be moved from one side to the other. Once the toilet has been moved to the reserve pit side, the “resting” pit is allowed to degrade and stabilize (see Figure 2-2 to Figure 2-6 for details at each site). Design and construction details can be found in the Korosan guidelines (https://niwa.co.nz/pacific-rim/research-projects/koro-sanitation-guidelines). The household was instructed in use of the toilets including periodic cleaning without damage to the inner surface of the bowl, collection and application of appropriate soil and organic mulch materials. This was backed-up with provision of an A4 laminated poster instructing users as to what should and shouldn’t be put down the toilet (as illustrated in Dakers et al. 2017d). Ongoing checks and guidance was also provided during the monitoring period.

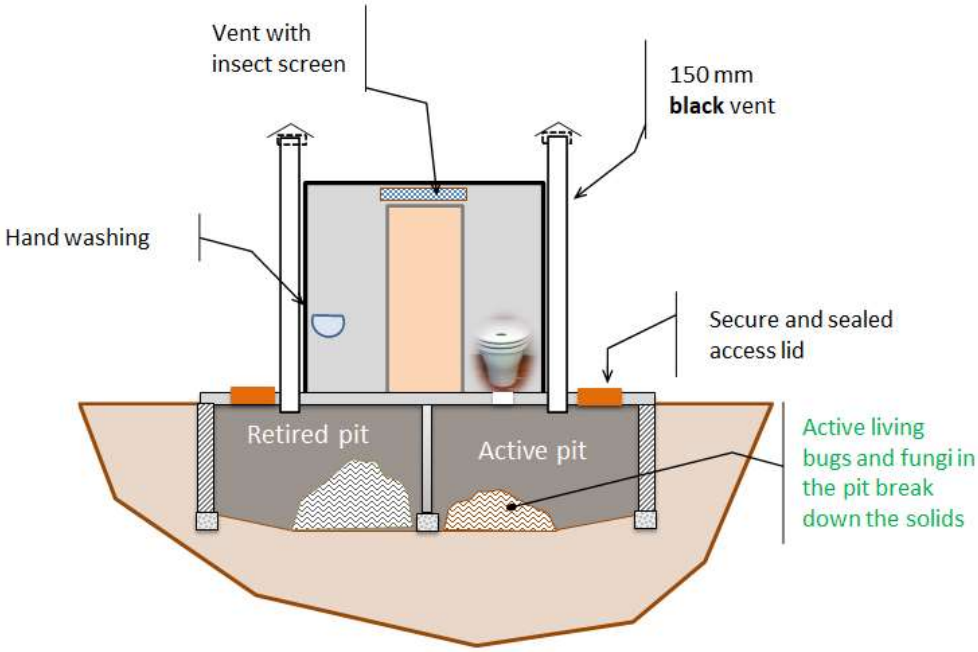


Figure 2-1: Schematic of ecoVIP2 pit latrine.

Figure 2-2: ecoVIP2 pit latrine with residents.

Figure 2-3: ecoVIP2 pit latrine showing vent pipe. Note the pipe has not yet been painted black, necessary to aid convective ventilation.

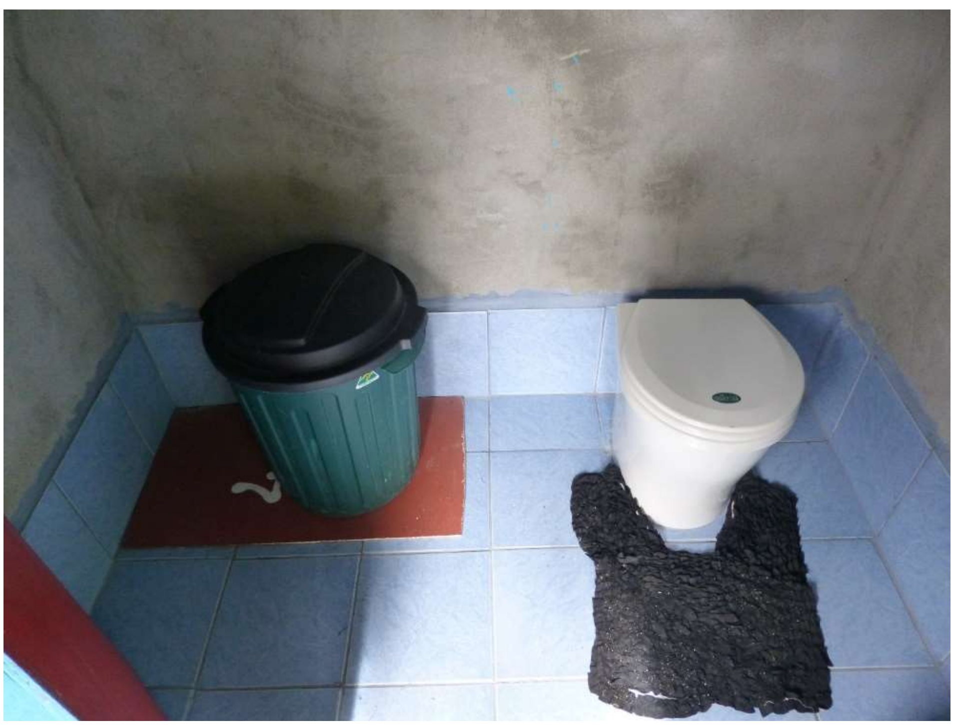


Figure 2-4: ecoVIP2 pit latrine interior tested in Namaqumaqua village.

Figure 2-5: ecoVIP2 pit latrine tested in Bavu village. During final stages of construction (left) before ventilation pipes fitted, and from back once completed (right) showing ventilation pipes.

Figure 2-6: ecoVIP2 pit latrine interior at Bavu. Note soil and mulch material available to add into the toilet after each use.

2.2 ecoVIP2 monitoring methods

An ecoVIP2 toilet was monitored in both Bavu and Namaqumaqua villages.

The height of the pile in each latrine was measured periodically in association with other sampling and visits to the village using a laser range finder from a standard height at the top of the latrine pedestal at intervals (May 2015 - Feb 2020 [Namaqumaqua], Jun 2018 - Feb 2020 [Bavu]). Physical sampling of the pit contents was undertaken on 8 occasions over a 6-month period (Jul - Dec 2017). A core sample was collected from the active pit using a section of pipe attached to a long pole (Figure 2-7) and placed in a plastic bag for visual assessment (i.e., colour, texture, smell and presence of invertebrates). The measurements of physical parameters included pH, moisture and ash. The chemical parameters tested included organic carbon and nitrogen and ammonia. The C:N ratio was calculated for each sampling round from a combined sample. Microbiological testing was done for *E. coli*. Techniques were based on APHA (2012) and are briefly described in Table 2-1. Combined humidity and temperature loggers were suspended at the base of the air vents where air exited the pit (representative of within the pit) and under the eaves of the latrine building (representative of outside the pit) at both Namaqumaqua and Bavu. The households using the ecoVIP2 were interviewed each time the pits were sampled and also during general visits to the village to identify any problems or nuisances such as odours or flies.

Figure 2-7: Jeremaia Koroijiuta (USP) showing the makeshift sampling tube used to take samples from accumulated faecal wastes in ecoVIP2 toilets.

Table 2-1: Pit latrine analyses.

Moisture	The sample was dried in an air oven at 105±2°C to a constant weight. Weight loss was equivalent to moisture content.
Ash	The sample was dried, charred and then heated in a muffle furnace at 550°C until only the inorganic material (ash) remained.
Organic Matter and C:N ratio	The organic matter content was estimated by difference as the loss-on-ignition from the dried sample when combusted in a muffle furnace at 550°C until only the inorganic material (ash) remained. The carbon: nitrogen ratio was then estimated assuming C comprised 50% of the organic matter (Pribyl, 2010).
Organic Nitrogen	The sample was digested with concentrated sulphuric acid and sodium sulphate to raise the boiling point and copper added as a catalyst to convert nitrogen in the sample to ammonium sulphate (semi-micro Kjeldahl method (Blakemore et al. 1987)). This was carried out in 50-mL calibrated test tubes inserted in a drilled aluminium block on a hot plate. Ammonium-nitrogen was determined in the digest by releasing the ammonium from alkaline solution through steam distillation. Collection of distillates in dilute boric acid was followed by titration with standardized hydrochloric acid to finally calculate for nitrogen.
pH	The basic measurement of electromagnetic pH measurement is the determination of the activity of the hydrogen ions by potentiometric measurement using a standard hydrogen electrode and a reference electrode. The apparatus was standardised against primary standard pH buffers and the sample was read.

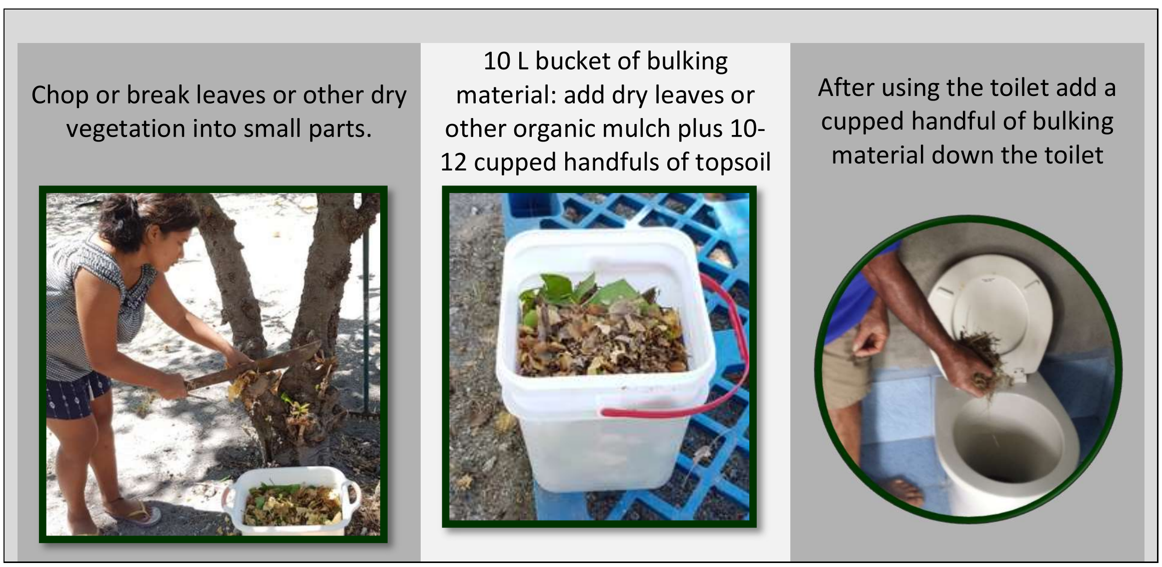


Figure 2-8: Organic bulking material for pit latrines.

2.3 ecoVIP2 results

The full dataset from pit sampling is presented in Appendix A, with change in pile height in the pit latrines shown below in Figure 2-9. There is a general increase in height over time, although some periods when pile height reduced are also apparent. These may be due to changing pile shape, compression of the faecal wastes and leafy debris used to encourage decomposition, and/or redistribution by liquid impact and the burrowing activities of worms and insects. The pile height at Namaqumaqua hovered around 0.5 m for the first 2 years then showed a gradual build up over the next 3 years to just over 1 m height (accumulation rate of 0.2 m yr^{-1}). The pile at Bavu rose more rapidly to 2 m over about 4 years (accumulation rate of 0.5 m yr^{-1}). The final height of the Bavu site was then close to reaching its practical maximum value, and so ready to move the toilet pedestal to the reserve pit.

The different accumulation rates observed are likely to be a reflection of the number of users and the amount and characteristics of the of mulch and soil material added. Both ecoVIP2 toilets were attached to a family home with 4-6 members. The Bavu toilet was additionally near to a mataqali (clan) meeting house and was extensively used during meetings which occurred a number of times each week. The Namaqumaqua toilet was also used by visitors from the nearby tourist hotel during cultural visits to the village, and by children waiting for the school bus at the entrance to the village each weekday. Both toilets therefore received greater use than the immediate households they served.

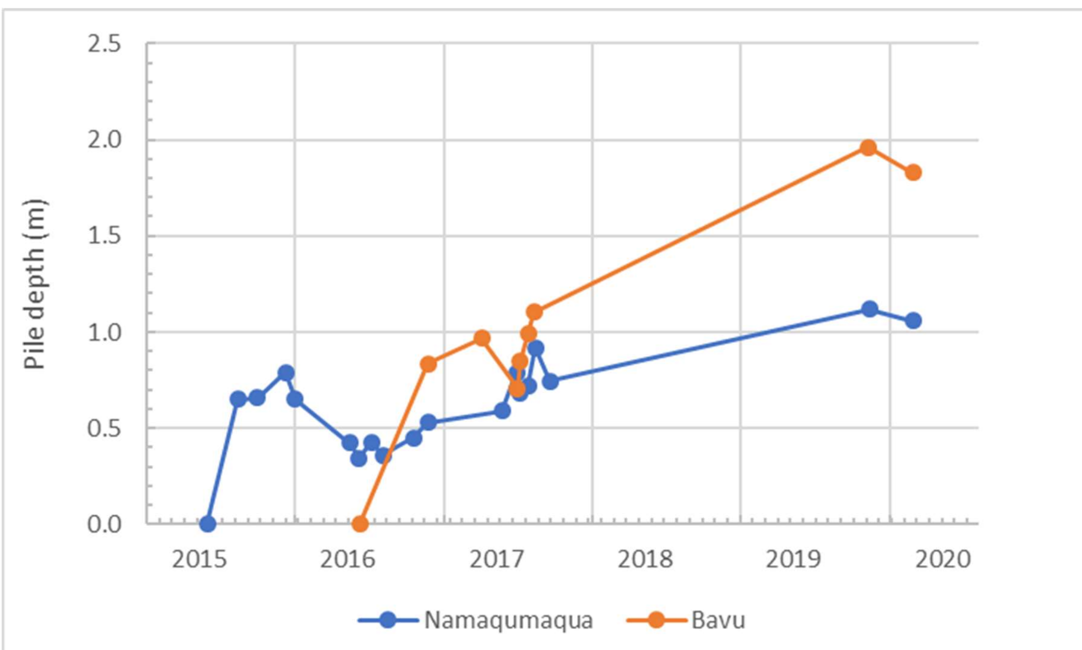


Figure 2-9: Change in faecal sludge pile height in the VIP latrines.

The humidity/temperature loggers operated properly for six months, but only at the Namaqumaqua site. Temperature is shown in Figure 2-10. The temperature record for a period between August and October 2016 shows distinct daily fluctuations, with the temperature inside the latrine (and below ground level) more stable. The relative humidity (RH) inside the latrine commonly ranged between 90-100% (Figure 2-11). As with temperature, RH exhibited a regular daily fluctuation, with greater fluctuations outside than inside the pit latrine.

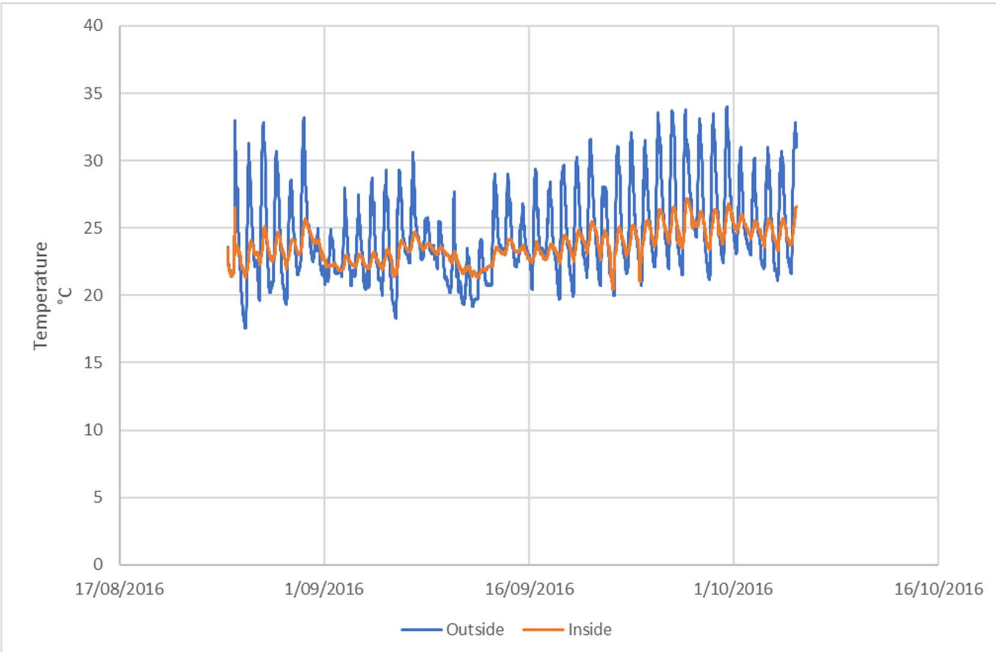


Figure 2-10: Temperature records for inside and outside the VIP latrines. Namaqumaqua site only.

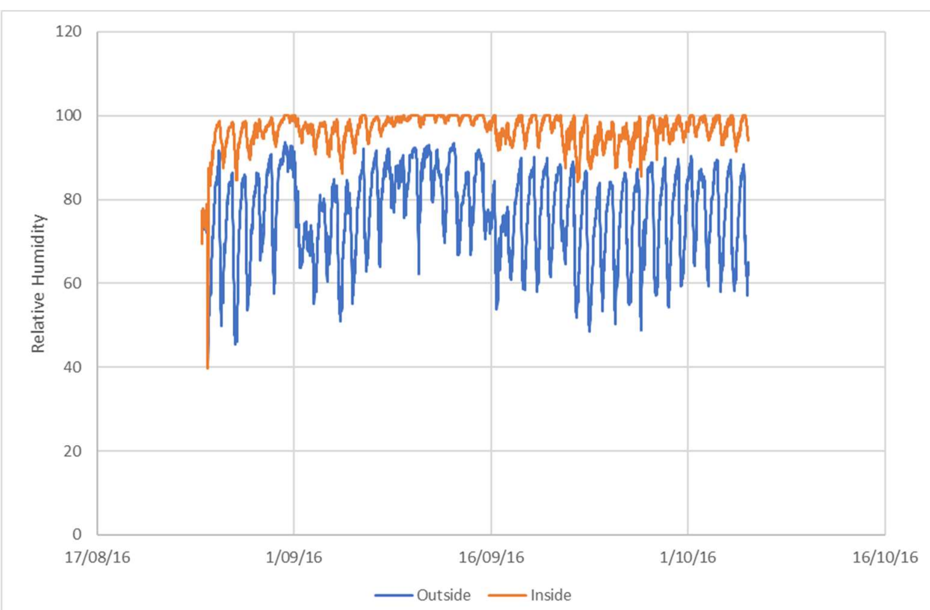


Figure 2-11: Relative humidity inside and outside the VIP latrines. Namaqumaqua site only.

The moisture content of the faecal sludge is shown in Figure 2-12, and ranged between 29.8 % and 77.1 %. Median values were 65.7 % at Namaqumaqua and 56.1 % at Bavu.

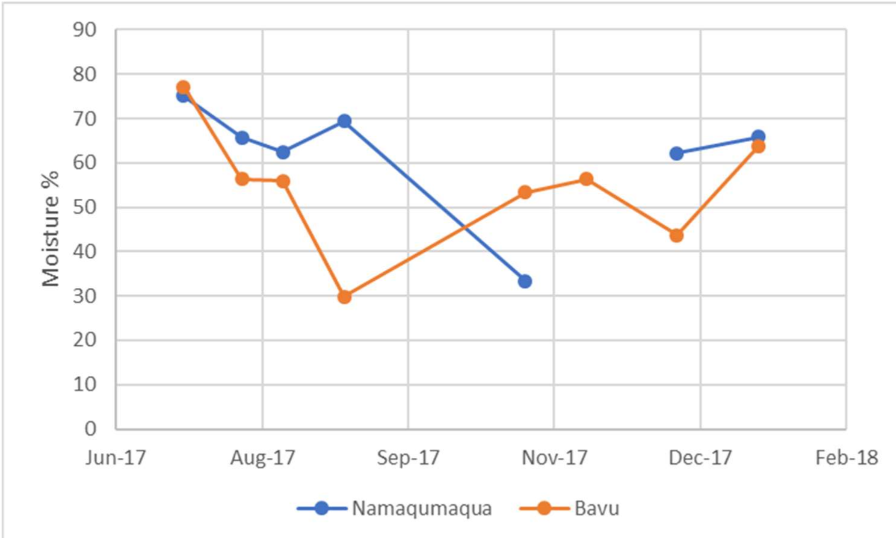


Figure 2-12: Moisture content of the VIP faecal sludge.

The pH of the piles is shown in Figure 2-13 and ranged between 7.0 and 7.6 at both sites.

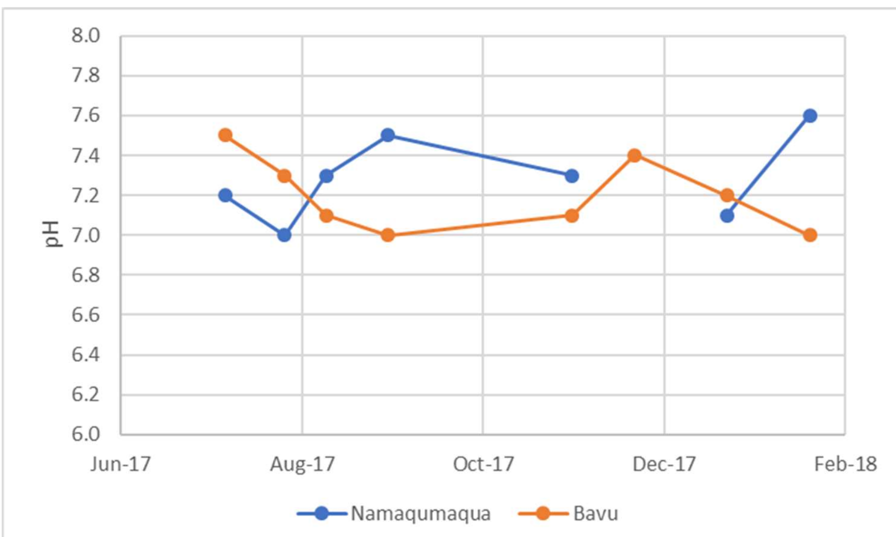


Figure 2-13: pH of the VIP faecal sludge.

E. coli data from the two pit latrines is presented in Figure 2-14. Concentrations ranged from 200 CFU 100 mL^{-1} (2.0 x 10^2) up to 1,600,000,000 CFU 100 mL^{-1} (1.6 x 10^9). Median concentrations were 34,000,000 CFU 100 mL^{-1} (3.4 x 10^7) at Namaqumaqua and 620,000 CFU 100 mL^{-1} (6.2 x 10^8) at Bavu.

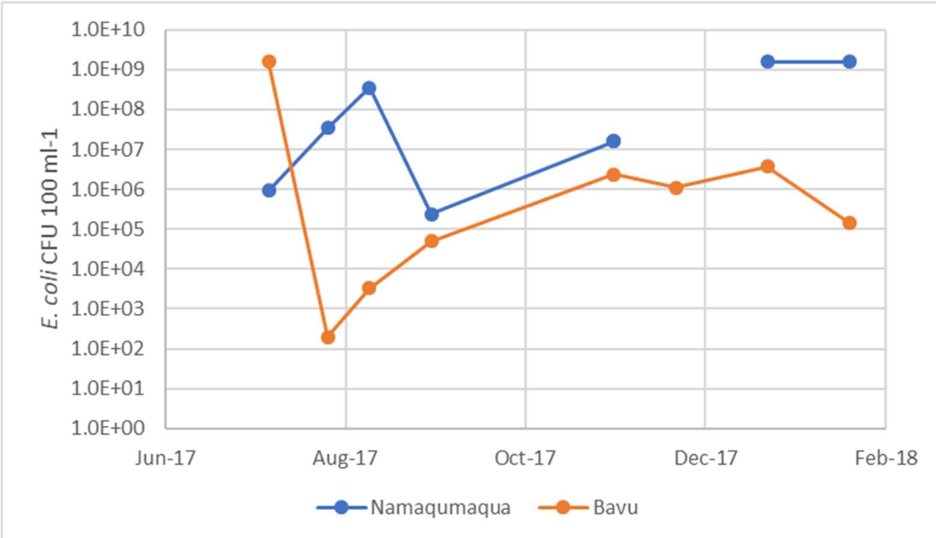


Figure 2-14: *E. coli* in the VIP faecal sludge.

Ash content (as measured by loss on ignition of dried samples) of the pit latrine samples is shown in Figure 2-15. The ash content at Bavu was higher (52-60%) and more stable than at Namaqumaqua (ranging between 37-67%).

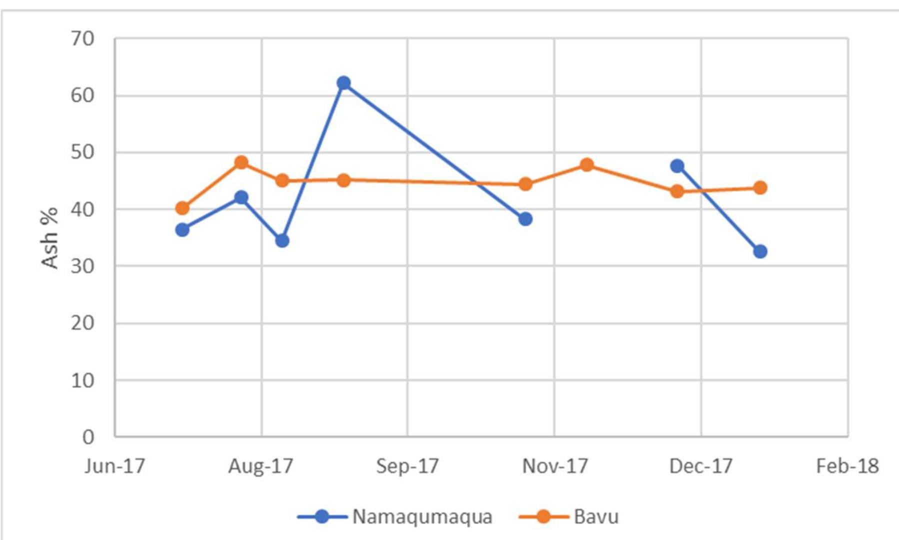


Figure 2-15: Ash content of the VIP faecal sludge.

The organic matter content of the pit latrine piles is shown in Figure 2-16. Median organic matter concentrations were 61.7 % at Namaqumaqua and 55.3 % at Bavu. The limited organic N measurements available showed a C:N ratio for the VIP faecal sludge ranging between 11 and 26 (Appendix A).

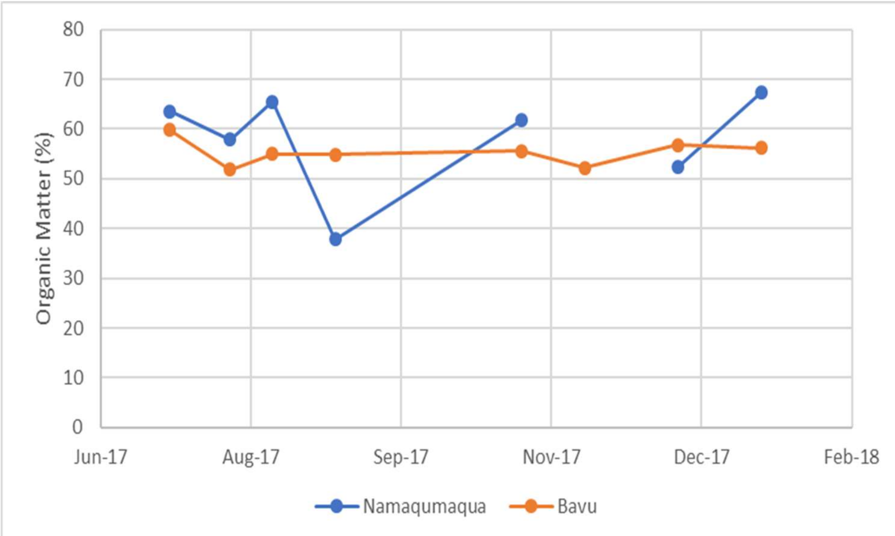


Figure 2-16: Organic matter content of the VIP faecal sludge.

Ammonia-N data was only available for a limited number of sample dates. The range of concentrations of ammonia-N was broad, from a minimum of 0.06 g m^{-3}, to a maximum of 263 g m^{-3} with median concentrations of 58.2 g m^{-3} at Namaqumaqua and 68.8 g m^{-3} at Bavu (Appendix A). No distinct patterns of concentration were evident from the limited number of data points. Neutral pH in the pile is likely to limit gaseous ammonia formation avoiding potential inhibition of microbial breakdown of the organic materials or the activity of the insects and worms assisting the process.

Visual observations of faecal sludge samples showed a rich colonisation of the pit material by insects, especially small beetles (Coleoptera), moth fly larvae (Lepidoptera), and some worms. In February 2020 larger insects including slaters and some cockroaches were observed on the more-mature outer edges of the sludge pile. There were no reports of insect pest problems by the users, but this is something that should continue to be monitored in the future.

2.4 ecoVIP2 discussion

Monitoring of the pit latrine focused on:

1. The accumulation rate of the faecal material, in order to assess the time it would take them to fill and therefore the frequency the two pits would need to be exchanged and the likely period filled pits would have to breakdown before resuming active service.
2. The composition of the faecal material, in order to assess the "health" of the decomposition process and identify any significant factors that may be influencing this.

When the active pit has become full the toilet pedestal reserve pit would be moved to the reserve pit and the faecal sludge in the full pit will be allowed to decompose. This subsequent phase of the study, including the reduction on sludge volume and die-off of microbial pathogens before excavation or reuse, was not able to be addressed within the timeframe of this study.

Odours were never obvious in the toilet buildings at either village when sampled or periodically visited. Odours from pile samples were only rarely reported, whereas on several occasions, samplers specifically noting a lack of odour. Insect problems were never reported over the period of monitoring. This is likely to reflect the owner's careful maintenance of the toilet systems, including the effective use of the mulch/bulking material, as well as the efficient functioning of the pit ventilation systems installed.

Insect and worms such as those observed in the decomposing faecal sludge are known to aid significantly in decomposition processes, substantially reducing biosolids accumulation and enhancing pathogen reduction rates (Furlong et al., 2014, Hill et al. 2013. Hylton et al. 2020, Lalander et al. 2015, Singh et al. 2019). In vermiculture systems urine-diversion is often employed to reduce toxic impacts of ammonia on worms. A rich insect fauna seems to have been able to survive in the faecal sludge pile of the ecoVIP toilets without such diversion. It is likely that men, in particular, may have urinated outside rather than in the latrine, reducing the urine load on the toilet. Although very high ammonium-N levels were measured on occasions in the faecal biosolids, pH remained relatively neutral during our study, limiting ionisation of ammonium to the more toxic free ammonia form. Also, the soil and organic mulch added to the toilets is likely to have provided a rich inoculum of fauna and buffered conditions in the pile, e.g., by providing additional complex carbon substrates (increasing the Carbon to Nitrogen (C:N) ratio), promoting drainage and aeration of the pile and adsorption of ammonium.

The temperature and relative humidity data within the pit chamber demonstrated the generally stable atmospheric conditions within the latrine. Temperatures between 22 and 27 °C and relative humidity commonly above 90% reflected the tropical climate and are expected to assist with decomposition of the pile. In addition, the pH of the pit material remained nearly neutral, which is conducive to rapid microbial decomposition.

Fresh faecal sludge is known to be highly variable in consistency and composition (Strande et al. 2014). It includes a heterogeneous assemblage of human wastes, anal cleansing materials and bulking agents of various age and composition in different stages of decomposition. This makes it hard to obtain a representative sample and explains the variability recorded in our sampling.

The moisture content of the VIP faecal sludge in the present study ranged between 29.8% and 77.1% at the two sites with medians of 66 and 56 % for at Namaqumaqua and Bavu respectively. This is generally lower than that of freshly voided faeces (63–86%; Rose at al. 2015). For faecal sludge in 10 VIP latrines In South Africa, Kreuger et al. (2021) report higher moisture contents between 70 and 80%, which are similar to those reported by Septien et al. (2018) at other sites. This suggests that either relatively less urine was being voided in the VIP toilet in the present study (conceivable given the outdoor nature of much village life), the faecal sludge piles were being relatively well-drained via the base of the pits, a greater quantity of bulking agents were being added providing greater moisture absorption, and/or the ventilation system in our systems was more efficient providing greater throughflow and drying. Reduced moisture contents are likely to enhance oxygen diffusion into the sludge, increasing its rate of decomposition (Bakare, 2014) and reducing the potential for odour generation.

Median organic matter content of around 60% (~30% Carbon) and C:N ratios typically in the range of 10-20 in the accumulating faecal sludge were more than double and ten-fold, respectively, that of raw faeces (Rose et al 2015). This likely reflects the ongoing addition of soil and mulch materials by toilet users. Faecal sludge organic C and N content in the present study were similar overall to that measured in VIP sludge in South Africa (Kreuger et. al. 2021) and Colorado, USA (Hafford et al. 2018).

Ammonia-N data was incomplete, however the data available showed high variability, with a minimum concentration of 0.06 g m^{-3}, and a maximum of 263 g m^{-3}. As noted previously, the variability is likely to be associated with difficulty in collecting a representative sample.

In the present study sludge height in the centre of the pile was measured using a laser measuring device. It is likely that the progression of pile height and volume may, in addition to net accretion, have been affected by changes in the distribution of sludge due to slumping, liquid impact, and the burrowing activities of worms and insects. A superior methodology would be the use of stereographic imaging techniques (e.g., Bakare, 2014; Bakare et al. 2015) which would have provided a more accurate measure of the changing volume of sludge. Bakare (2014) found sludge accumulation rates between 120 and 550 L yr^{-1} (average 282 L yr^{-1}), with a per capita accumulation of 56 L per person yr^{-1}.

Despite these limitations to our sampling regime, it was obvious that overall decomposition processes in the ecoVIP2 toilets were operating very effectively. The first pit at Namaqumaqua was still less than half full after 5 years use, and the more intensively used pit at Bavu was ready for change-over after 4 years of intensive use. Utilising double pit systems with extended periods before pit emptying is required can substantially reduce hazards associated with handling and use of pit biosolids (Fleming, 2017). Further monitoring during the resting period is needed to determine the reduction in pile height, and the need for subsequent emptying of the pit. There is potential for the biosolid residuals to reduce sufficiently so as to avoid the need for sludge excavation for a number of fill and rest cycles. *E. coli* concentrations measured in the faecal sludge covered a very wide range, which is likely to reflect different composition and freshness of the samples obtained. Some samples may be dominated by decomposed material, while others may have a greater content of fresh faecal material. *E. coli* levels were often relatively high at 10^6 cfu $(100 \text{ mls})^{-1}$ or greater. Further sampling of *E. coli* during the resting phase is warranted to determine the rate of disinfection, and the health status of the composted pit material.

Information on survival of pathogens, particularly long-lived helminth propagules (e.g., *Ascaris* sp. ova), in the stabilised biosolids from these systems is also needed to guide safe use or disposal. This information will help assess the longer-term safety, sustainability, maintenance requirements and costs of these systems.

The small volume of outflow infiltrating from the base of the pit was not monitored in the present study. This discharge is likely to be relatively concentrated compared to septic tank effluent, but of much lower volume, providing the pit is properly located away from surface and subsurface inflows and above the groundwater table. The outflow from a pit toilet is likely to be mainly from urine. Providing all urine is voided in the household toilet (unlikely when people are working outside the house, children are at school, etc.,) and assuming evaporation losses from the pit are relatively minor this would generally mean approximately 1 -1.5 L per person/d (Friedler et al. 2013), or around 6-9 L/d for a 6 person household (about the same volume as one flush of a low volume water-flushed toilet). Although latrines discharging to groundwater are often perceived to be a significant danger to the microbiological status of groundwater used for drinking (Graham and Polizzotto, 2013), a number of recent studies have shown that the risks are low outside the contaminated near-field area compared to other routes of transmission, providing the pit base is well above the water table and reasonable separation distances are applied from groundwater wells and surface waterways (Back et al. 2018, Mara, 1996, Ravenscroft et al. 2017).

3 Septic tank effluent quality and sludge accumulation rates

Blackwater septic tank effluent quality and sludge accumulation rates were assessed in Votua, a coastal village of around 50 houses with a population of nearly 300 people. Full details of the wastewater treatment infrastructure installed are detailed in Dakers et al. (2014). Assessment of the water quality and structural integrity of these septic tanks was an integral component of upgrading the total village system, which is detailed later in section 5. As there is limited data on blackwater septic tank systems, the data has been combined here with data from septic tank sampling undertaken at a second village, Namaqumaqua, where sampling of septic tanks was undertaken as part of monitoring the performance of subsequent land application treatment systems.

3.1 Septic tank system description

Existing septic tanks in Votua and Namaqumaqua that were structurally sound, water-tight, of sufficient size, and without excessive sludge build-up were targeted. Each septic tank was fitted with an Ecotube™ outlet filter (Ecogent Ltd, Auckland, NZ) to reduce suspended solids carry-over.

Figure 3-1: New prefabricated septic tanks being installed in Votua village in early 2010.

3.2 Septic tank monitoring methods

3.2.1 Effluent quality methods

Effluents from existing septic tanks in Votua village were sampled from the outlet pipe in May (2 houses) and November 2007 (4 houses and village hall) to assess potential loadings on the proposed wetland treatment system. Further new prefabricated septic tanks were installed in the village so all houses were serviced (see Figure 3-1). Effluent from the two additional septic tanks at Namaqumaqua village were also sampled as part of the monitoring of subsequent land application systems (Section 4). Samples for dissolved nutrient analysis were filtered on site and along with unfiltered samples transported on ice to the IAS Laboratory at the University of the South Pacific in Suva for final analysis.

3.2.2 Sludge accumulation rate methods

New precast, dual-chamber septic tanks installed in Votua village were subsequently measured for sludge accumulation on two occasions, once in 2015 and as part of an audit of a further eight new septic tanks in November 2016. This was about five and six years, respectively, after commissioning. Filters were cleaned, and surface mats and sludge depths were measured in the first chamber of the septic tanks (Figure 3-2; Figure 3-3) as outlined in Dakers 2017c).

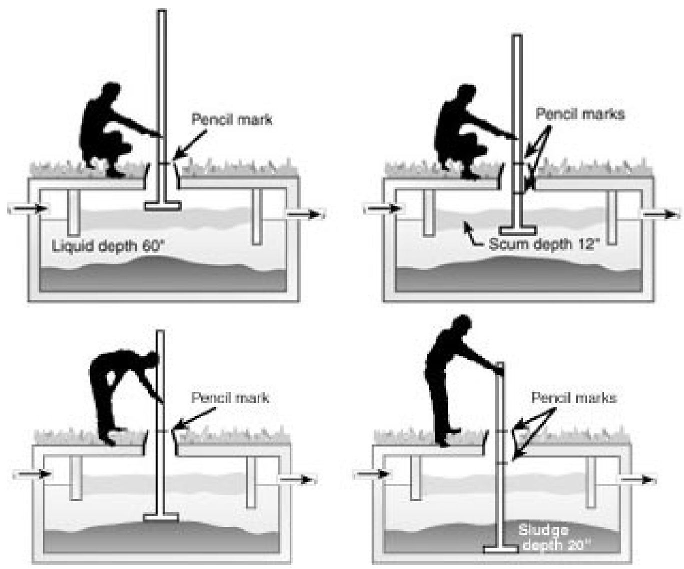


Figure 3-2: Method for determining the scum and sludge depths in septic tanks. A 2 m long, 15 mm diameter PVC probe with a tee on one end was inserted into the first chamber of the septic tanks to determine the upper and lower levels of the scum (top) and sludge (bottom) layers, and by difference calculate their depths (Source: Schultheis 2001).

Figure 3-3: Auditing septic tank sludge accumulation. Assessing scum and sludge depths (left) and cleaning septic tank outlet filters (right).

3.3 Septic tank results

Septic tank effluent data from the two Fijian villages is summarised in Table 3-1 along with data reported for blackwater and combined black and grey waters systems in other studies. The full data record for the present study is provided in Appendix C. Results for Fijian village blackwater septic tank effluent showed high variability, with elevated concentrations of organic matter (BOD_5), suspended solids, nutrients and faecal indicator bacteria compared to those reported from elsewhere for systems treating combined househoild wasterwaters. The pH was relatively neutral with a high percentage of the nitrogen present as ammonium.

The accumulated depth of the surface mat and the sludge layer measured in the first chamber of the Votua septic tanks is summarised in Figure 3-4. It shows comparatively low rates of sludge accumulation in the bottom of the tanks. The surface scum layer was well developed but not excessive. Negligible sludge or scum accumulation was measured in the second chambers of any of the septic tanks.

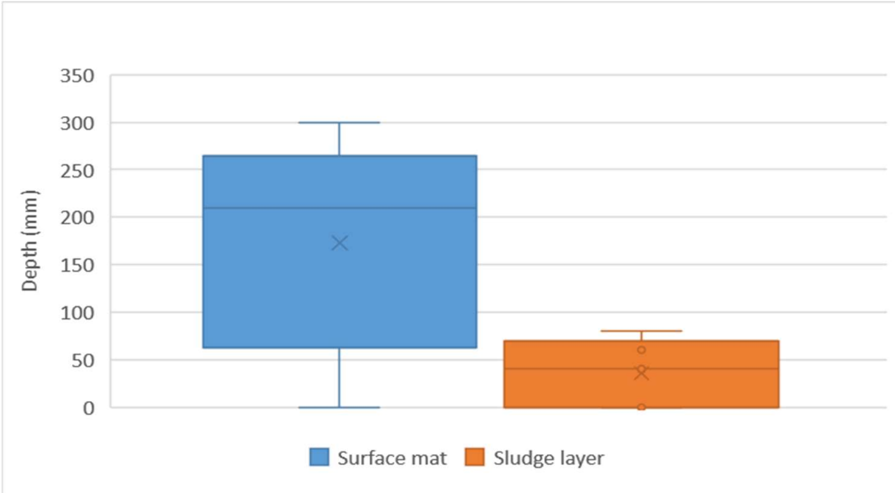


Figure 3-4: Depth of surface mats and sludge layers in septic tanks after 5-6 years operation. See Appendix A, Figure A-1: Box and whisker graph explanation.

Table 3-1: Water quality data ranges for septic tank effluent at Votua and Namaqumaqua compared with values reported elsewhere. Median values are shown in parenthesis for the blackwater data.

Data source	BOD_5	TSS	pH	Conductivity	TP	RDP	TKN	NH_4-N	Faecal coliforms	*E. coli*
	g m^{-3}	g m^{-3}	(pH units)	µS cm^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	cfu 100 mL^{-1}	cfu 100 mL^{-1}
Blackwater only										
Votua (7 sites)	58–363 (65)	9–729 (50)	6.7-7.6 (7.1)	597–3340 (1489)	13.7-30.6 (22.15)	11.3–99.8 (33.1)	46–341 (147)	43–309 (133)	22,000–2,800,000 (1,300,000)	40,000–1,600,000 (790,000)
Namaqumaqua (2 sites)	9–122 (80)	8–303 (80)	NA	NA	17–32 (26.3)	1.5–28 (22)	143–269 (205)	143–225 (203)	NA	2,400,000–37,700,000 (7,960,000)
Gold Coast, NSW, Australia (n= 6 sites). Goonetilleke et al. (2002)#	45-440 (180)	80-940 (253)	NA	NA	21-86 (48)	NA	97-748* (460)	NA	NA	NA
Combined black and greywater										
USEPA (1980)	7–480	8–695	NA	NA	NA	NA	9–125*	NA	NA	NA
ENSIC (1982)	90–130	40–74	7.0–8.1	NA	20	NA	19–35	14–25	NA	NA
Mara and Sinnatamby (1986)	160	90	7.1	NA	18	NA	32*	27	10,000	10,000
Crites and Tchobanoglous (1998)	100–140	20–55	NA	NA	12–20	NA	50–90	30–50	NA	NA
USEPA (2002)	138–217	49–161	NA	NA	11–22	NA	39–82	NA	40,000–160,000,000	NA

Range and (median) for six properly functioning septic tanks without excessive sludge accumulation. Range reported here corresponds to 10 and 90 percentile values.

* TN values.

3.4 Septic tank discussion

3.4.1 Septic Tank effluent quality

Blackwater is generally reported to be of higher strength than greywater (Friedler et al. (2013), Henze and Ledin (2001), Masi et al. (2010). Effluent quality for septic tanks treating blackwater and their associated sludge accumulation rates have rarely been recorded under tropical conditions or for Pacific Island communities. Effluent quality for 9 dual chamber septic tanks in 2 Fijian villages was within the lower 80% of the range reported for 6 properly functioning blackwater septic tanks under subtropical conditions on the Gold Coast of Australia (Table 3-1). The international data for septic tanks treating combined household wastewaters (including greywater from showers, basins and laundries) generally shows a narrower range of effluent quality than seen for Votua and Namaqumaqua, as might be expected. In particular, TP, TKN and ammonia-N levels were higher than generally reported elsewhwere for septic tanks receiving combined black and greywater. However, USEPA (1980, 2002) report wider ranges for most parameters than found in other studies, so the Fijian data ranges of BOD_5 and faecal coliforms fall within the USEPA “expected range” of values, while TSS was only a little higher (at Votua) than the USEPA values.

The elevated contaminant levels present in blackwater septic tank discharges, particularly for ammonium-N, nitrogen, phosphorus and faecal indicator bacteria, show that these effluents are still of very high strength and pose a serious risk to human and ecosystem health if allowed to discharge to surface waters. They also have a high potential to clog soak pits and soil infiltration systems and contaminate groundwaters.

Side-by-side studies such as Nasr and Mikhaeil (2013) show that well-sized dual chamber septic tanks such as those monitored here, that provide more than the minimum residence times for solids settling, will provide improved removal of organic matter (BOD_5) and total suspended solids, phosphorus than single chamber tanks, and greater mineralisation of organic nitrogen. The improved effluent quality from these systems reduces stress on subsequent land application and disposal stages and lowers the risk of their failure.

3.4.2 Septic tank sludge accumulation rates

The five new dual chamber septic tanks examined in 2015 after about 5 years’ service all had low levels of scum and sludge accumulation compared to what would be expected in New Zealand. The eight septic tanks examined in 2016 (after about 6 years’ service) showed surface scum depths of 140 to 190 mm (accumulation rate of 35–42 mm yr^{-1}) and sludge depths from negligible (2 septic tanks) to 90 mm depth (accumulation rate of 7-8 mm yr^{-1}). It was noted that those septic tanks with high dwelling occupancy formed heavy surface scum but very little settled sludge. The moderate scum levels suggest significant fat and oil loads to the septic tanks, and possibly use of innappropriate materials for anal cleansing, such as newspaper or cloths that do not readily disintergrate and sink in the tank.

Real world septic tank sludge accumulation rates are notoriously difficult to measure accurately, varying markedly depending on design and loading rates as affected by relative volume of the septic tank in relation to usage patterns (e.g., numbers and age of users) and factors such as diet type and materials used for anal cleansing (Strande et al. 2018). Data for septic tanks receiving only blackwater from flush toilets is particularly rare, with most of the results reported in the literature for mixed domestic wastewater including greywater.

The dual chamber septic tanks examined in Votua in 2016 conformed to the AS/NZS 1547:2012 standards and had a relatively large volume compared to those specified in previous Fiji standards (Medical Department 1964, Ministry of Housing and Urban Development, 1990). Controlled experimental studies have measured reduced rates of sludge accumulation with increasing residence time or relative septic tank volume and for baffled than unbaffled septic tanks (Nasr and Mikhaeil, 2013). Higher decomposition rates and slower sludge build-up have also been recorded at elevated temperatures such as experienced in Fiji (Mara and Sinnatamby, 1986, Mills et al. 2014).

The sludge accumulation rates measured in the present study were generally very low when compared to typical sludge depth accumulation rates in New Zealand or other temperate climates (Gray, 1995). This suggests that smaller septic tank sizes than specified in the AS/NZS 1547:2012 Standards and used in the KoroSan guidelines for Fiji (Dakers et al. 2020a) may still function adequately under Fijian conditions. However, given the practical challenges and significant costs involved in desludging septic tanks in Fijian villages, and the general reluctance to undertake such maintenance, there are good reasons to encourage the use of larger septic tank volumes. The resultant longer sludge residence times will significantly reduce the total quantity of sludge requiring disposal and increase the period before desludging will be required (Gray, 1995, Nasr and Michaeil, 2013) Based on our measurements, desludging intervals in excess of 10 years are likely under tropical Fijian conditions. Additionally, the degree of sludge stabilisation achieved, and so risk posed by the sludge removed will be reduced when it is disposed of or reused. Use of septic tank outlet filters to reduce solids carryover, as recommended in the KoroSan guidelines (Dakers et al. 2020a) provides a safeguard for subsequent land application treatment and disposal stages (Crites and Tchobanoglous, 1998).

Based on the limited septic tank audit results collected in the present study we recommend that:

1. Septic tanks installed in Fiji should ideally be sized as recommended in the AS/NZS 1547:2012 Standards and KoroSan guidelines (Dakers et al. 2020a). It is likely that such septic tanks will be able to operate for an extended period without needing desludging.

2. Septic tank outlet filters should be fitted and checked and cleaned every 6 months.

3. Sludge and surface mat accumulation should be checked every 5 years.

4. The septic tank should be pumped out when the sum of the sludge and surface mat thickness is greater than half the tank depth below the outlet invert level, or, the surface mat thickness is within about 50 mm of the top of the outlet filter. Some residual sludge should always be retained in the tank to seed the continued operation of the system after emptying.

4 Land application systems

4.1 Land Application System description

The performance of two land application systems (LAS) was investigated in Namaqumaqua, a coastal village on the Coral Coast of Viti Levu (Figure 1-1). Site assessments were made as outlined in Dakers et al. (2017a and 2017b). The seaward side of the village sits on free-draining soil with a high content of coral sand, and the landward side of the village sits on poorly draining soil with a high content of loam and clay. LAS systems were constructed at two houses (one from each soil type) based on the KoroSan #4 guidelines (Dakers et al. 2020b), as outlined in Dakers (2014a). A schematic overview is shown in Figure 4-1. The LAS consisted of trenches intermittently dosed with effluent from existing household septic tanks via a perforated pipe laid over either the existing coral sand subsoils (seaward sandy site; House 1) or a 400 mm deep layer of imported coarse coral sand laid over a drainage layer of coarse coral wrack known locally as laselase (landward clay site, House 2). Wastewater exiting the septic tank entered a small flout chamber, which intermittently dosed the trenches via 2 perforated distribution pipes laid in parallel along its length.

The trenches at the clay site were built up above the existing soil (Figure 4-2) and had a perforated drainage pipe set just above the base to drain any excess flow which was not able to infiltrate into the clay soil below. This was piped into a natural wetland area. There was evidence of occasional episodic outflow from this pipe, but never during our sampling or periodic visits. The sides of trenches were lined with concrete block walls and sealed over with a concrete cover to provide an airspace vault above the sand layer. Palm fronds were laid over the surface to form an organic mulch to encourage colonisation by worms and insects.

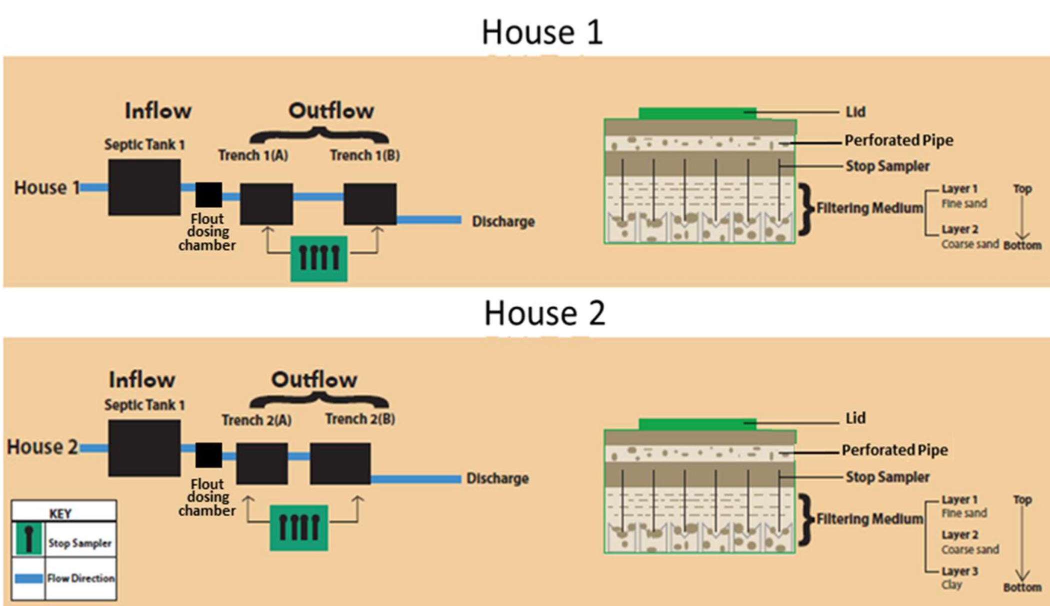


Figure 4-1: Process flow diagram for Namaqumaqua land application systems.

Figure 4-2: Land application trenches sampled in Namaqumaqua showing inspection hatches. The House 1 LAS (left) was set into the existing sandy soils on the seaward side of the village, and the House 2 LAS (right) was set in a raised bed above the clay soils and shallow water table on the landward side of the village

4.2 LAS monitoring methods

Inspection hatches were set in the flout chambers and at 2 locations along the LAS trenches to enable sampling (Figure 4-3). Each trench had 4 groundwater sampling devices installed (Fullstop™ wetting front samplers, CSIRO, Australia[2]) prior to sampling. Sampling was undertaken on 5 occasions over a 4-month period (Aug- Nov 2017). On each occasion, 5 L of septic tank wastewater (Figure 4-4) was sprinkled into a ~1.0 m^2 area (2.0 m x 0.5 m) of the LAS trench using a watering can to simulate a 5 mm application dosing cycle triggered by accumulated household wastewater. After each dosing a 50 ml plastic syringe was attached to the groundwater sampler to extract a ~20 ml sample of the percolate captured in the sampling device at the base of the trench. Problems with blockage of the sampling devices were experienced on a number of occasions requiring their extraction, cleaning and reinstatement before sample collection. Measurements of pH, conductivity, dissolved oxygen and temperature were taken from each sample, which were then combined to provide sufficient volume for further analysis. The samples were then returned to the laboratory by road in ice filled, insulated containers. Filtered samples were analysed for NH_4-N, NO_2-N, NO_3-N and DRP while unfiltered samples were analysed for TKN, TSS, BOD, TN, TP, P-PO_4 and *E. coli* using standard methods (APHA, 2012).

[2] http://www.fullstop.com.au/

Figure 4-3: Raised bed LAS sampling point for House 2 clay soil site. Wastewater dosing distribution pipes (white) pushed to side of trench. Fullstop™ samplers and tubes enabled samples to be drawn from the bottom of the sand filter.

Figure 4-4: Septic tank effluent being collected from the Flout chamber. The effluent was then manually sprinkled over a section of the LAS sand filters to simulate a dosing cycle. The filtrate emerging at the base of the sand bed was later collected via the Fullstop™ samplers.

Figure 4-5: Addition of wastewater during system sampling using a watering can. Syringes can be seen attached to the FullStop^{TM} sampling devices (arrowed) to enable samples to be drawn from the base of the bed.

4.3 LAS results

Results for each site are presented in Appendix D. In some instances, there were anomalies in the reported laboratory results. For instance, where values for TKN (a combination of organic-N and ammonia-N) were less than for ammonia-N. Wherever possible these errors have been adjusted or otherwise omitted. In Appendix D these have been highlighted in red.

The median TSS in the septic tank effluent was 57 g m^{-3} in House 1 and 104 g m^{-3} in House 2 (**Figure 4-6**). At the two sampling sites in the infiltration trenches at House 1, median TSS was reduced by 84% and 77% to 9 g m^{-3} and 13 g m^{-3} respectively. At House 2, median TSS was reduced by 75% and 90% to 26 g m^{-3} and 10 g m^{-3} respectively.

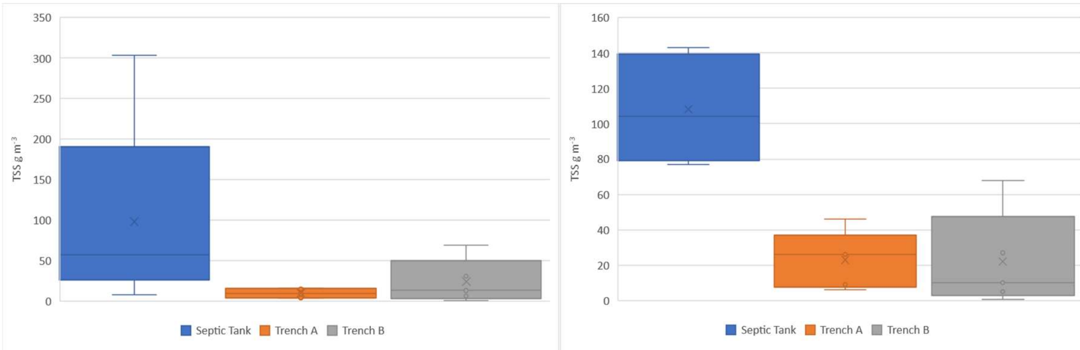


Figure 4-6: Box and whisker plots of total suspended solids from House 1 (left) and House 2 (right). See Appendix A, Figure A 1 for explanation of box and whisker graph format.

The median BOD_5 in the septic tanks were 97 g m^{-3} in House 1 and 66 g m^{-3} in House 2 (Figure 4-7). Median BOD_5 values were reduced by 77% and >81% to 22 g m^{-3} and <18 g m^{-3} in the infiltration trenches at House 1, and by 71% and >73% to 19 g m^{-3} and <18 g m^{-3} at House 2.

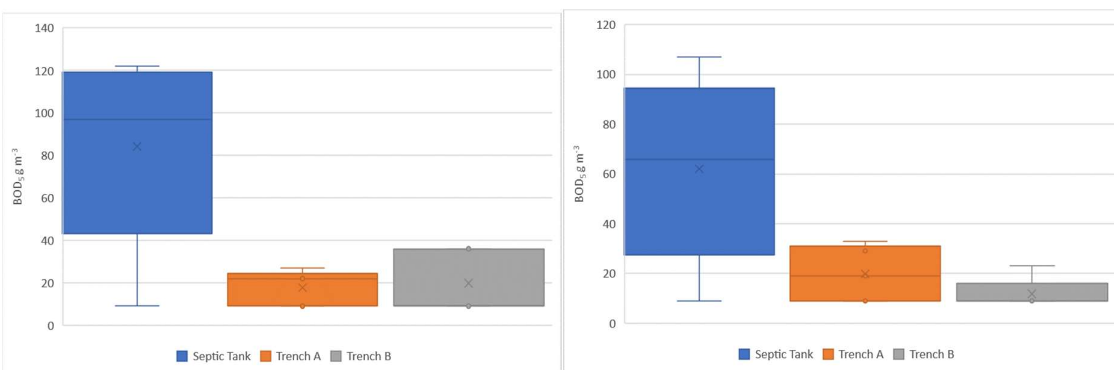


Figure 4-7: Box and whisker plots of BOD_5 from House 1 (left) and House 2 (right) at each stage of the treatment system. See Appendix A, Figure A 1 for explanation of box and whisker graph format.

Median total nitrogen concentrations in the septic tank effluent was 241 g m^{-3} in House 1 and 191 g m^{-3} in House 2[3] during the monitoring period. (Figure 4-8). At House 1, nitrite-N and nitrate-N were only reported on two occasions for the septic tank effluent. On both occasions these oxidised forms of nitrogen were very low (<0.3 g m^{-3}), which is as expected.

At House 1, median TN was reduced by 92% at both sampling sites in the infiltration trenches down to 18.9 and 18.4 g m^{-3} respectively[4]. At House 2, median TN was reduced by 86% and 74% to 26 g m^{-3} and 49.6 g m^{-3}.

[3] TN is the sum of TKN, nitrate-N and nitrite-N. On occasions the reported laboratory values for TN were well in excess of these summed concentrations. As the TKN analysis is designed for effluents, it is considered more reliable than the TN analysis. Thus TN values have been adjusted to be the sum of TKN, nitrate-N and nitrite-N.

[4] Note that the median is shown as a horizontal line in the graphs, and that the mean in trench A is much higher than the median due to highly skewed data.

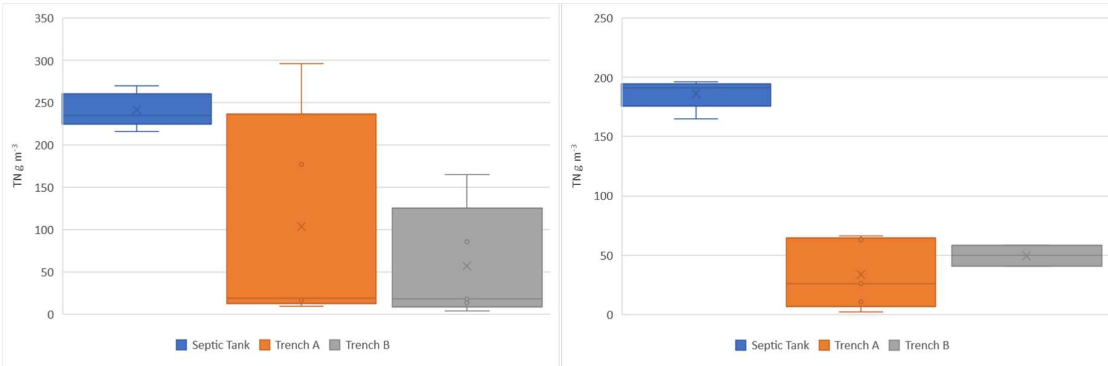


Figure 4-8: Box and whisker plots of total nitrogen from House 1 (left) and House 2 (right). See Appendix A, Figure A 1 for explanation of box and whisker graph format.

Ammonia-N comprised a high proportion of TN in the septic tank effluents, with median concentrations of 217 g m^{-3} at House 1 and 175 g m^{-3} at House 2 (Figure 4-9) during the monitoring period. Median ammonia-N concentrations were significantly reduced in the trenches at both houses. At House 1, median effluent values were 1.0 and 0.8 g m^{-3}, equivalent to reductions of 99.5-99.6%. At House 2, median effluent values were 0.09 (both trench areas tested), equivalent to reduction of 99.95%. By way of comparison, the Department of Environment general discharge standard for ammonia-N is 10 g m^{-3}, and for significant ecological zones it is 5 g m^{-3}(DoE, 2007) Thus these systems readily meet both standards.

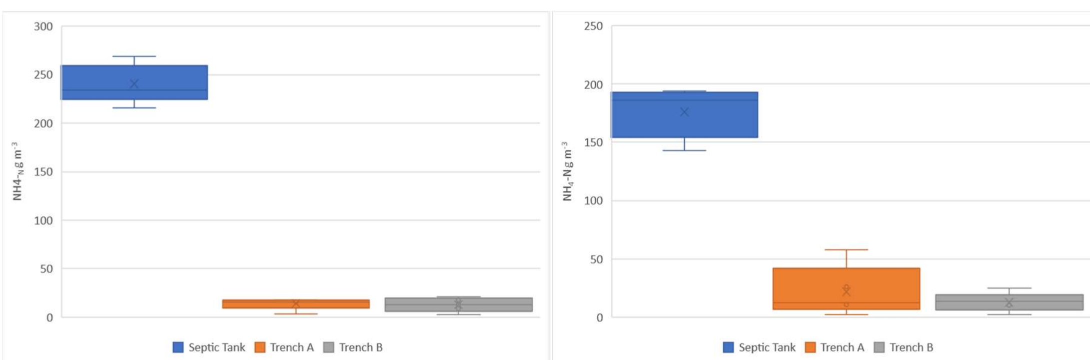
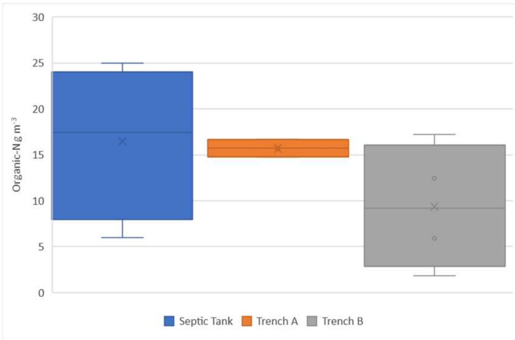


Figure 4-9: Box and whisker plots of ammonia nitrogen from House 1 (left) and House 2 (right). See Appendix A, Figure A 1 for explanation of box and whisker graph format.

Organic-N was calculated by difference (TKN – ammonia-N). In the septic tank of House 1, concentrations ranged from 6 g m^{-3} to 25 g m^{-3}, with a median of 17 g m^{-3} (Figure 4-10). Removal was 10% at position A and 47% at position B. At House 2, only a single value for organic-N was able to be calculated, and thus valid removal calculations were not possible.



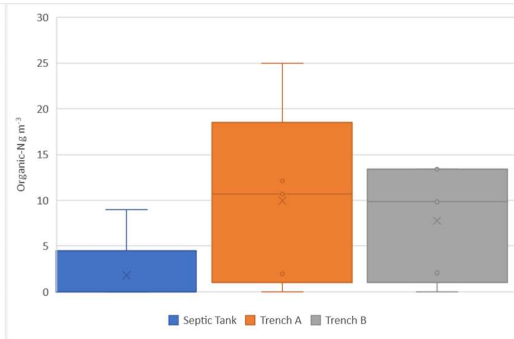
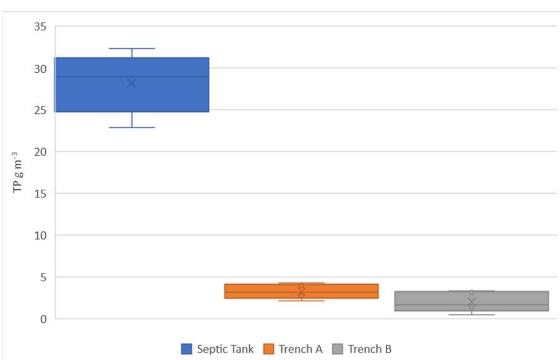


Figure 4-10: Box and whisker plots of organic nitrogen from House 1 (left) and House 2 (right). See Appendix A, Figure A 1 for explanation of box and whisker graph format.

Oxidised forms of N (nitrate-N and nitrite-N) were only reported for the first two sampling occasions. They were low (<0.2 g m^{-3}) in all instances. At House 1, nitrate-N increased substantially to 161 g m^{-3} and 278 g m^{-3} at position A, and 74.1 g m^{-3} and 147 g m^{-3} at position B on the two sampling occasions. This shows significant microbial nitrification of the ammonia in the septic tank effluent was occurring during passage through the subsequent sand filters. At House B, nitrate-N concentrations were also variable, at 51 g m^{-3} and 2.7 g m^{-3} in position A, and 44.7 g m^{-3} and 11 g m^{-3} in position B. Elevated levels of nitrite-N were measured on one occasion at House B, reaching 6.1 g m^{-3} and 4.9 g m^{-3} (position A and B respectively).

Median TP concentrations in the septic tank effluent were 29.0 g m^{-3} and 25.2 g m^{-3} (Figure 4-11), during the monitoring period, of which 23.2 g m^{-3} (80% of TP) and 21.4 g m^{-3} (85% of TP) comprised soluble RDP (Figure 4-12) (House 1 and 2 respectively).



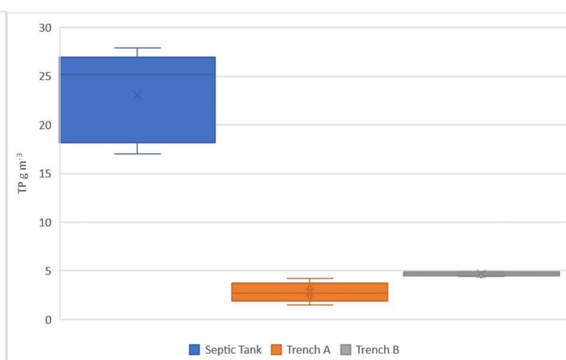


Figure 4-11: Box and whisker plots of total phosphorus from House 1 (left) and House 2 (right). See Appendix A, Figure A 1 for explanation of box and whisker graph format.

Removal of TP based on median values was 89% and 94% at position A and B respectively at House 1, with median effluent concentrations of 3.1 g m^{-3} and 1.7 g m^{-3}. The DoE TP standard for General discharge is 5 g m^{-3}, and for a Significant Ecological Zone is 2 g m^{-3}. RDP removals were similar at 89% and 95% respectively (median effluent concentrations of 2.6 g m^{-3} and 0.9 g m^{-3}). At House 2, removals of TP were 89% and 81% at position A and B respectively, with effluent concentrations of 2.7 g m^{-3} and 4.7 g m^{-3}.

Thus if these systems were directly discharging to a waterway, they would consistently meet the General discharge standard but only partially meet the requirements for significant ecological zones. Removals of RDP were 95% and 83% in position A and B respectively, resulting in median RDP concentrations of 1.1 g m^{-3} and 3.7 g m^{-3}.

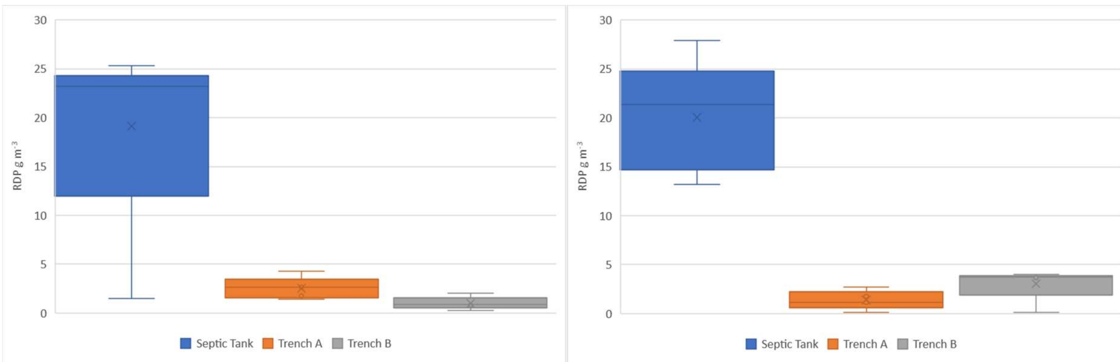


Figure 4-12: Box and whisker plots of reactive dissolved phosphorus from House 1 (left) and House 2 (right). See Appendix A, Figure A 1 for explanation of box and whisker graph format.

E. coli influent and effluent concentrations for House 1 and House 2 are shown in Figure 4-13 (shown as log values). The range of influent concentrations at both houses were fairly similar (Appendix D, House 1, 7,600,000 – 9,800,000 cfu 100 ml^{-1}; House 2, 2,40,000 – 37,700,000 cfu 100 mL^{-1}). At both sites, reduction in *E. coli* concentrations were also similar, at around 2.0 – 2.5 orders of magnitude (99.4 -99.7%) based on median values (median effluent concentrations of 11,100 cfu 100 mL^{-1} to 50,900 cfu 100 ml^{-1}. Although substantially lower than *E. coli* discharged from septic tanks, the land applications system discharges would still not meet DoE *E. coli* standards for direct discharge to water (general discharge or to a significant ecological zone). Proper disposal to ground or further treatment (e.g., in a wetland) would be required for safe disposal.

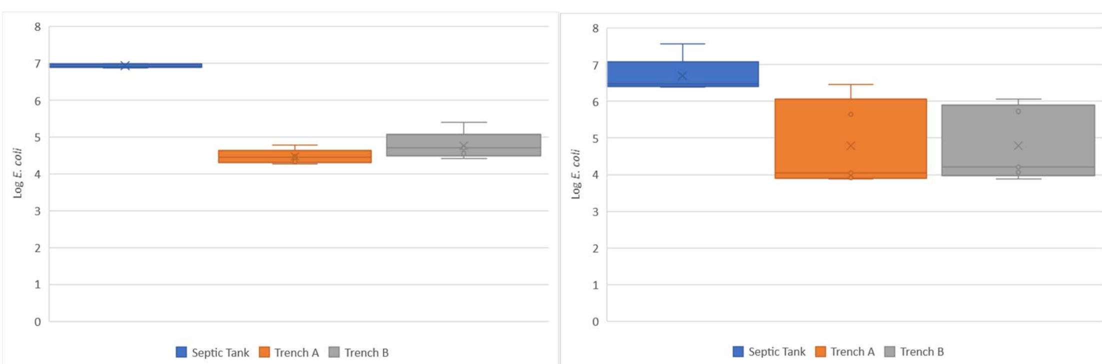


Figure 4-13: Box and whisker plots of *E. coli* from House 1 (left) and House 2 (right). See Appendix A, Figure A 1 for explanation of box and whisker graph format.

4.4 LAS discussion

The infiltration trenches at both houses were effective at reducing key contaminants. TSS was reduced by between 75% and 90% during passage through the sand filter, with median final effluent concentrations between 9 g m^{-3} and 26 g m^{-3}. Removal is expected to be mainly associated with physical filtration through the matrix of coral sand and associated biofilms.

Median BOD_5 concentrations reduced between 71% and >81% with outflows between <18 g m^{-3} and 22 g m^{-3}. Various removal mechanisms are likely to contribute to this. Physical filtration of particulate BOD_5 is a key initial removal mechanism. Passage through the largely aerobic infiltration trench promoted microbial degradation of dissolved and particulate BOD_5.

Median TP concentrations reduced between 81% and 94%, whereas RDP reduced by between 83% and 95%. Both dissolved and particulate fractions were removed during passage through the infiltration trench matrix, it is likely that both physical filtration as well as binding to sorption sites have contributed to the observed removal.

Reduction in median TN concentrations ranged between 74% and 92%. Organic-N was only 5-7% of total nitrogen, thus physical filtration of particulate nitrogen can only have contributed in a minor way to the observed removals. Reduction of ammonia-N concentrations, and increases in nitrate-N, and to a lesser extent nitrite-N, indicate nitrification was an important transformation mechanism within the trenches. It is likely that denitrification was the subsequent “removal” mechanism, due to the significant reduction in TN concentrations, and the absence of other potential mechanisms such as plant uptake.

These treatment results are generally consistent with other evidence for shallow intermittent sand filter treatment systems (e.g., Crites and Tchobanoglous, 1998). Wild et al. (2006) have shown, compared to the silicate sands, substantially greater colonisation of microbes in complex surface structure of highly porous calcareous coral reef sands such as those employed in the present study. Tait et al. (2013) found similar levels of N and P removal from wastewaters in similar calcareous sand media in Rarotonga, with simultaneous nitrification and denitrification measured using stable isotopes. Very high removal of faecal bacterial and viral indicators has also been measured for similar coral sands sourced from Tarawa, Kiribati under both unsaturated (Humphries et al. 2020) and saturated flows (Burberry et al. 2015).

It is likely that further reductions in BOD_5, nutrient and microbial contaminants will occur during passage through the biomat at the soil surface beneath the sand filters and the vadose zone below (Beal et al. 2005, Gill et al. 2009, Lusk et al, 2017, Siegrist et al, 2000), and within groundwater aquifers before discharge plumes reach surface waters. These are likely to substantially reduce potential human health and ecological risks (e.g., Pang et al. 2004, Robertson et al. 2019). However, cumulative impacts at high housing densities may still be significant and down-gradient groundwater drinking sources would need significant set-back distances.

5 Village-scale constructed wetland treatment system

5.1 Constructed wetland description

A village-scale wastewater treatment system was installed at Votua, a coastal village of around 50 houses with a population of nearly 300 people. Full details of the wastewater treatment infrastructure completed in 2010 are detailed in Dakers et al. (2014). In brief, blackwater from each household and village hall toilets are initially treated in septic tanks before discharging to a village sewer network. This is connected by gravity to two pump chambers and subsequently pumped to a constructed wetland complex (see Figure 5-1). Greywater from houses is disposed of separately, via coral rock-lined seepage pits (see Dakers et al. 2017e). Existing septic tanks were initially pumped out, cleaned and assessed. Those tanks that were structurally sound, water-tight and of sufficient size, were retained. For houses without septic tanks or with substandard septic tanks, new dual chamber precast concrete septic tanks (Arrow Group, Lautoka, Fiji) were installed, either 1.6 m^3 for single houses or 3.5 m^3 for two houses (Figure 3-1). All septic tanks were fitted with Ecotube™ outlet filters (Ecogent Ltd, Auckland, NZ) to reduce suspended solids carry-over.

The main village pump station (refer Figure 5-2) was fitted with a shredder pump which delivered to a header tank situated above the vertical flow constructed wetland (VFCW) approximately 200 m inland behind the village. The effluent then entered a flow dosing chamber (fitted with an alternating Flout™ which has a “floating outlet”, Figure 5-3 and Figure 5-4). The flout chamber dose loads ~600 litres of settled wastewater, alternating between two cells (each 170 m^2 in area) of the vertical flow wetland (VFW) via a pipe distribution network (6 mm orifices at 600 mm centres) (Dakers et al. 2014). The VFWs are filled with a base layer of coarse gravel, followed by fine gravel, and then topped with coarse sand (Navua rough sand, D10 0.41 mm, D60 2.1 mm, uniformity coefficient 5.12) with a fine gravel layer on the surface. The underdrain system set in the coarse gravel layer at the base of the wetland encouraged aerobic conditions between dosing events conducive to aerobic breakdown of organic matter and nitrification of ammonium nitrogen.

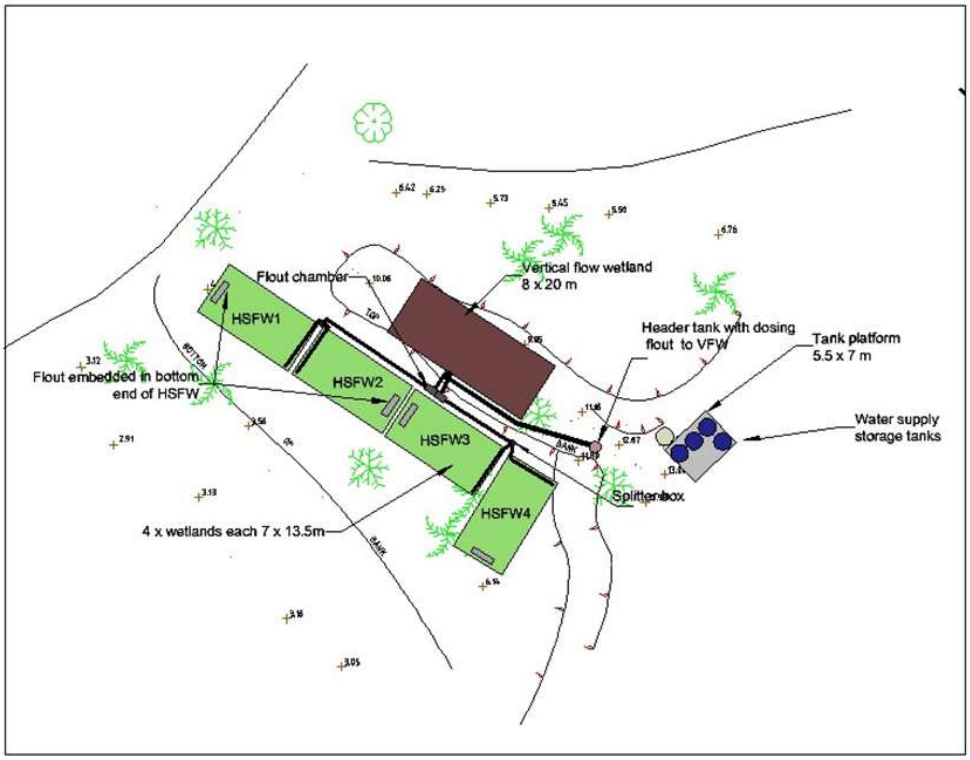


Figure 5-1: Schematic of constructed wetland complex at Votua.

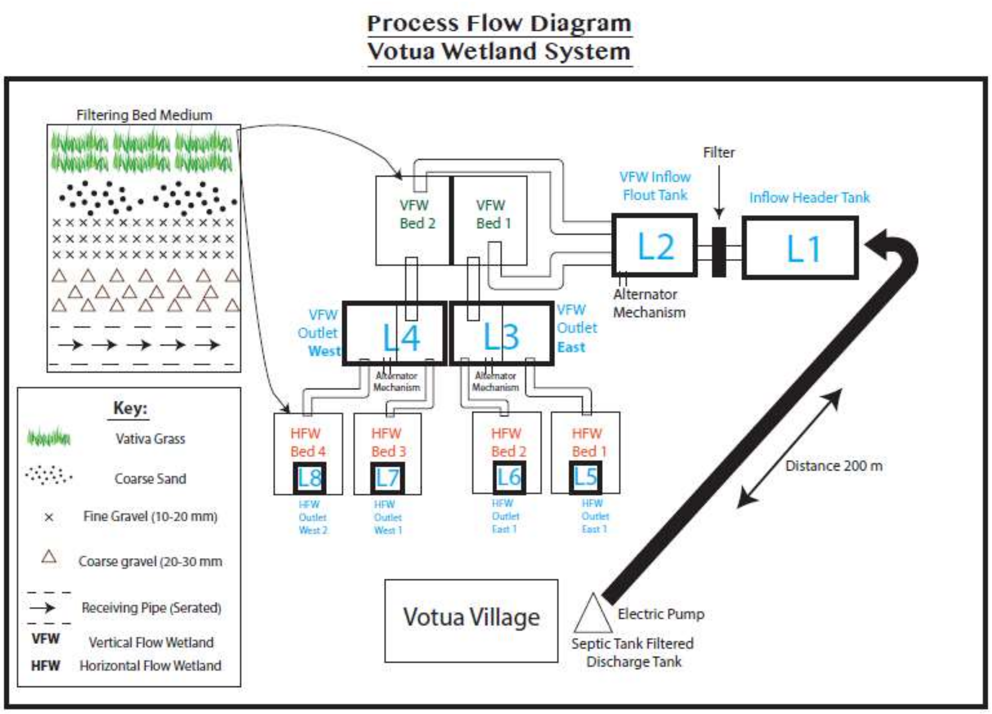


Figure 5-2: Process flow diagram of Votua wetland system showing sampling points L1-8.

The outlet from each VFW flows into another alternating flout chamber which doses one of two horizontal flow constructed wetland bed (HFW, four beds in total, each 94.5 m^2). The HFW beds were filled with 400 mm of fine gravel media (Figure 5-5). Permanently saturated conditions within the HFW encourages anoxic conditions, promoting processes such as denitrification.

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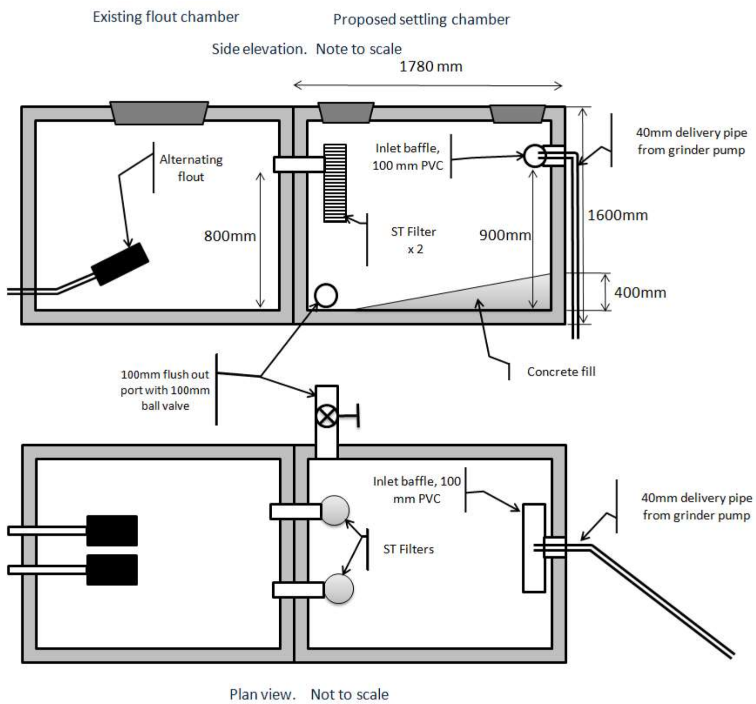


Figure 5-3: Schematic of the alternate dosing flout chamber.

Figure 5-4: Alternating flouts in VFCW dosing chamber.

All the wetlands were planted with umbrella sedge (*Cyperus involucratus*) sourced from the USP lower campus in Suva. Figure 5-6 and Figure 5-7 show the established wetland vegetation.

Figure 5-5: Votua Vertical flow wetland during construction. The photos show basal drainage pipes being covered in gravel (left) and surface dosing pipes (right).

Figure 5-6: Vertical flow wetland vegetated with umbrella sedge. Note dosing pipes which disperse the flow across the surface of the wetland.

Figure 5-7: The four horizontal-flow wetlands (left) and two vertical-flow wetlands (top right) in April 2011.

5.2 Constructed wetland monitoring methods

The wetland system at Votua was monitored approximately fortnightly on 10 occasions between June and October 2017. Grab samples were collected at the inflow header tank, the vertical-flow inflow flout chamber, the east vertical-flow outflow tank, the west vertical-flow outflow tank, and the two east horizontal-flow outflow tanks (L1-L8; Figure 5-2). There was never outflow from the west horizontal flow wetlands, likely due to seepage losses through the clay lining of the wetland. Samples were measured for pH, EC, DO and temperature on site and then transported in an ice filled, thermally insulated container to the Institute of Applied Sciences laboratory in the Faculty of Science, Technology and Environment at University of the South Pacific in Suva. Unfiltered samples were analysed using standard methods (APHA, 2012) for TKN, TSS, BOD, TN, TP, and *E. coli,* while filtered samples were analysed for NH_4-N, NO_2-N, NO_3-N and DRP.

5.3 Constructed wetland results

Full data for the Votua constructed wetland is shown in Appendix E and summarised below. We note that in several of the later sampling occasions, wastewater strength was quite low, such that the laboratory has had to prioritise which analyses to do. This unevenness of the number of results must be kept in mind in discussion and interpretation of the data. In general, median data is referred to as it is less affected by skewed results. In some instances, the laboratory has reported total Kjeldahl nitrogen values less than ammonia nitrogen. Where this has occurred, we have replaced the TKN value with the ammonia-N value.

Total suspended solids

Total suspended solids (TSS) data in the inflow header tank was highly skewed (Figure 5-8), with a median of 229 g m^{-3} but a mean of 2579 g m^{-3} due to a few extremely high values. It is likely that these samples were taken during or immediately after pumping of effluent from the village sumps. Median values had fallen to 67 g m^{-3} (71% reduction) in the vertical flow wetland dosing chamber. After the vertical flow wetlands (VFWs) TSS had reduced to 4 and 3 g m^{-3} in the east and west systems respectively. Values were a little higher after the horizontal flow wetlands (HFWs), at 7 and 5 g m^{-3}, with net reductions of 97% and 98%. It should be noted that on several sampling occasions there was no flow exiting the HFWs.

Biochemical oxygen demand

Five day biochemical oxygen demand (BOD_5) showed a median of 45 g m^{-3} in the header tank, reducing to less than 18 g m^{-3} (the laboratory detection limit) in the flout dosing chamber and remaining consistently below this value after passage through the VFW and

HFWs (

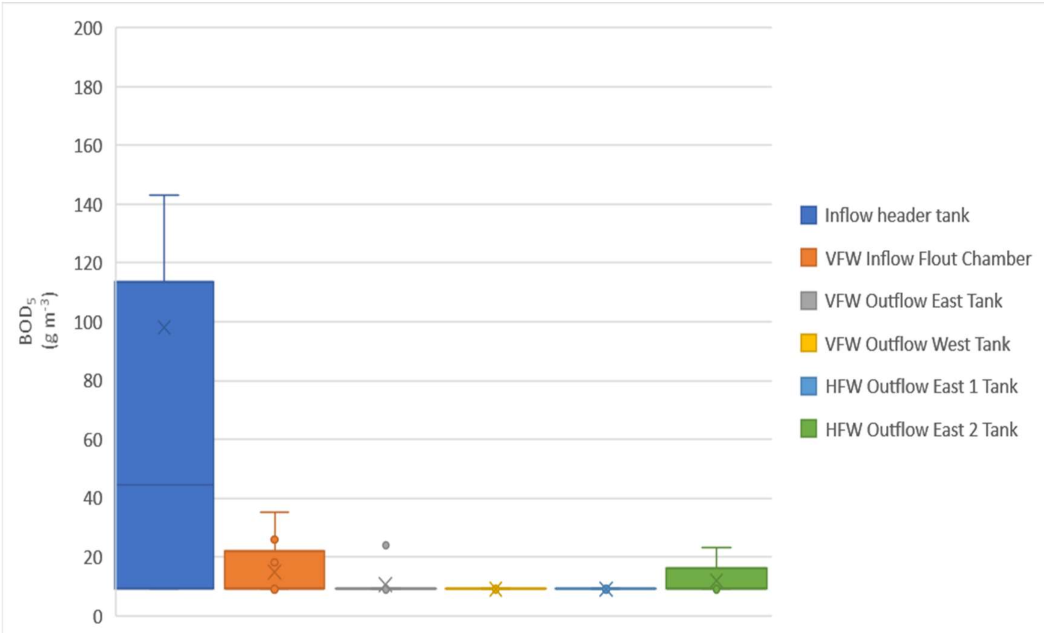


Figure 5-9). Overall removals were >80% in both the east and west systems. It appears that a substantial proportion of the BOD_5 that would have been present in the septic tank discharges was degraded during storage in the village sumps and the VFW header tank before application to the wetland.

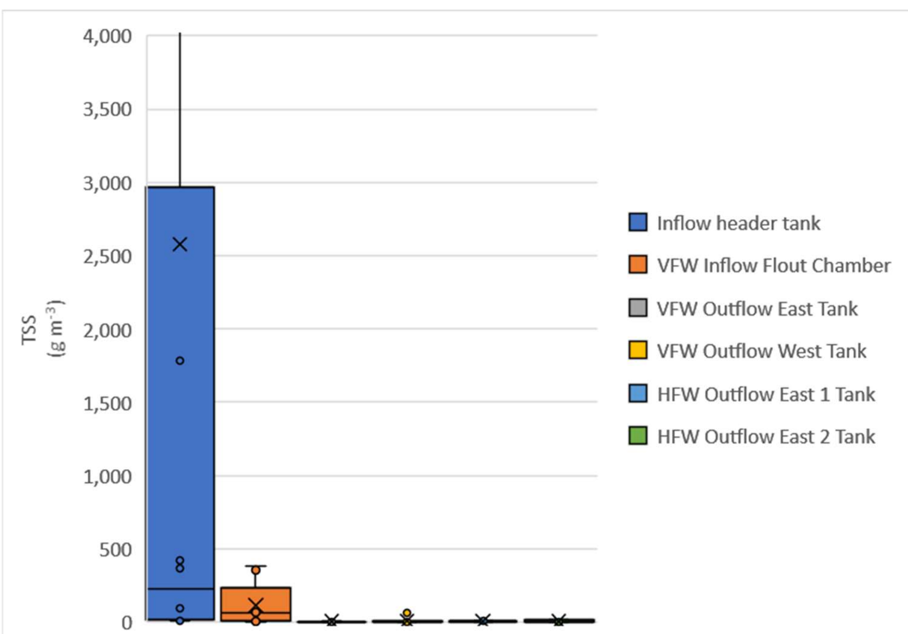


Figure 5-8: Box and whisker plot of total suspended solids in Votua constructed wetland. See Appendix A, Figure A 1 for explanation of box and whisker graph format.

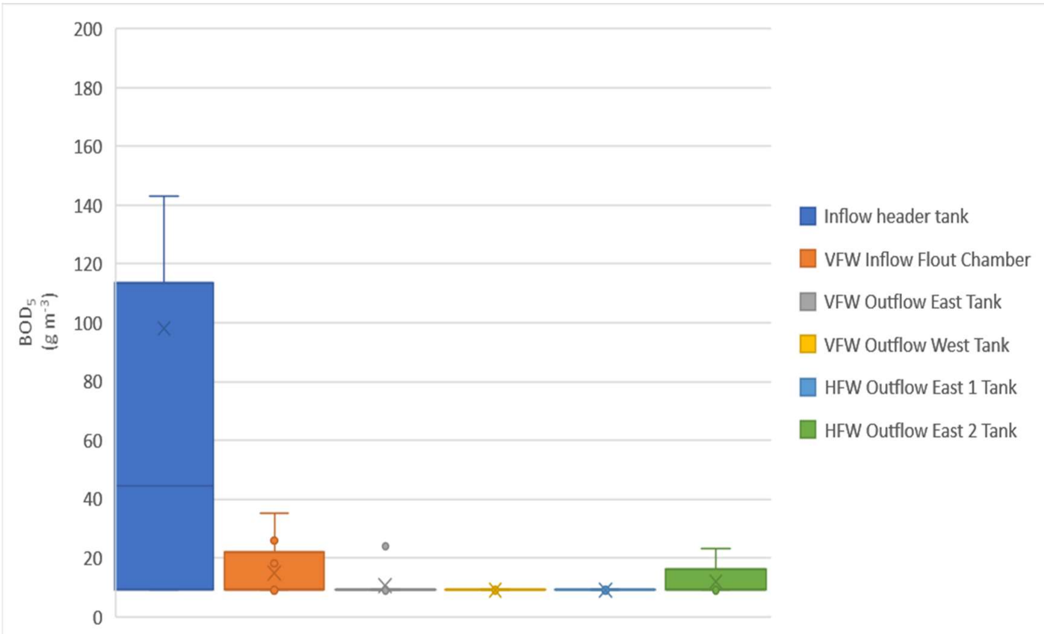
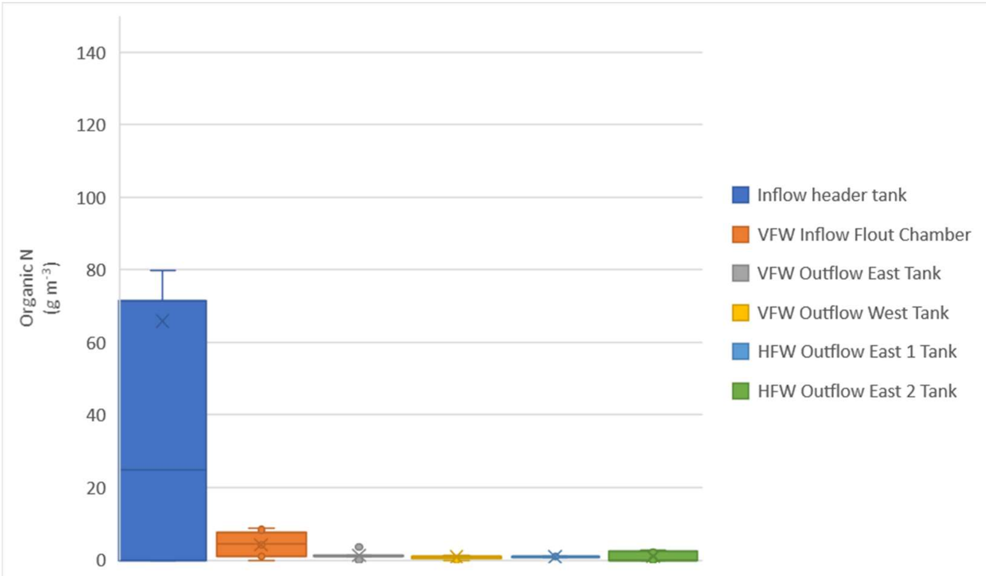


Figure 5-9: Box and whisker plot of BOD_5 in Votua constructed wetland. Note: Many of the BOD values for later stages of the treatment system were below the laboratory's detection limit. See Appendix A, Figure A 1 for explanation of box and whisker graph format.

Nitrogen

The VFWs were effective at conversion of reduced forms of nitrogen (ammonia-N and organic-N) to nitrate-N (median nitrate-N of 7.2 g m^{-3} and 8.3 g m^{-3} for the East VFW and West VFW respectively, Figure 5-11). A general lack of sample data from the later stages of the system make it difficult to have great confidence in median or mean values from these stages. There is a general pattern of increased concentrations of oxidised forms of nitrogen (Figure 5-11) as would be expected, but also some apparent regeneration of ammonium N in the HFWs on occasions (Figure 5-10). Nitrite-N concentrations were low compared with nitrate-N, with a maximum recorded of 1.13 g m^{-3} in the Header tank.



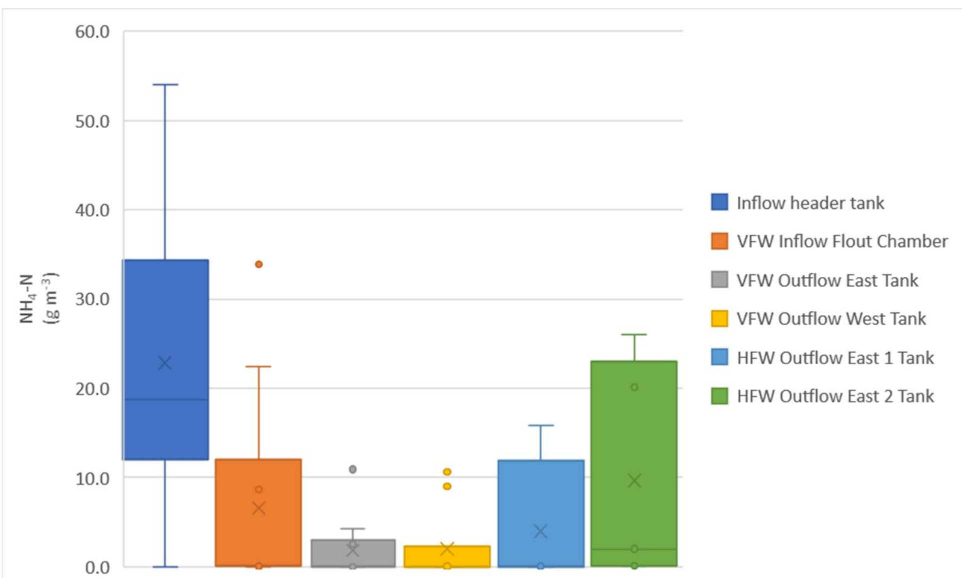


Figure 5-10: Box and whisker plots of organic-N (top) and ammonia-N (bottom) concentrations in the Votua constructed wetland. See Appendix A, Figure A 1 for explanation of box and whisker graph format.

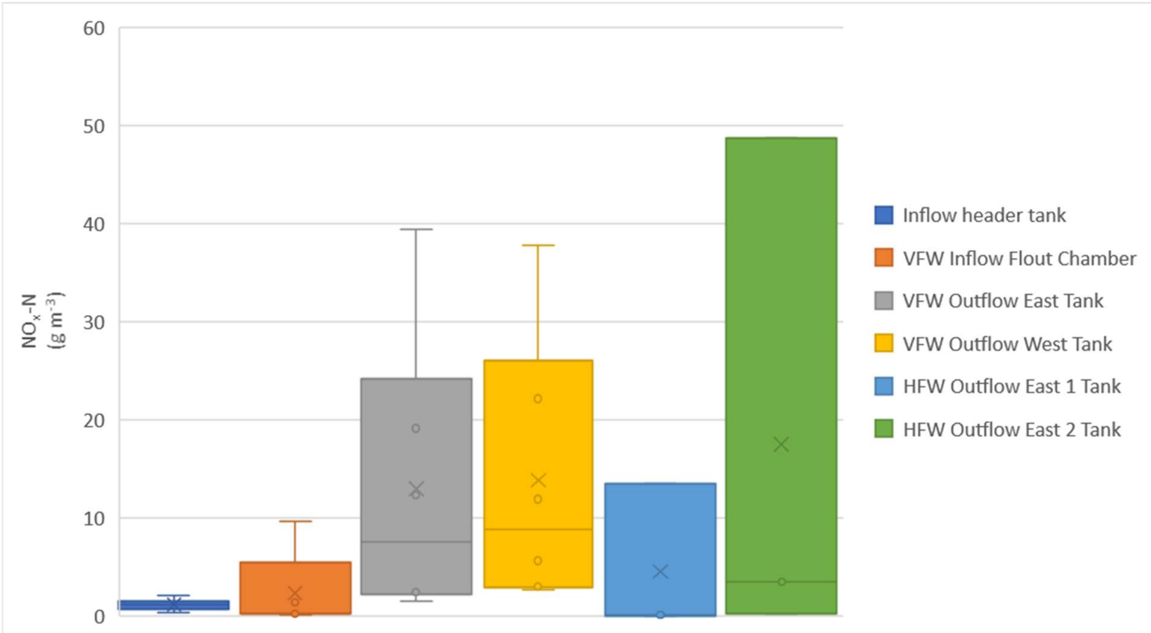


Figure 5-11: Box and whisker plots of total oxidised nitrogen concentrations in Votua constructed wetland. See Appendix A, Figure A 1 for explanation of box and whisker graph format.

The median total nitrogen in the inflow header tank was 60.3 g m^{-3}, reducing to 3.7 g m^{-3} and 3.8 g m^{-3} in the East and West VFWs respectively (Figure 5-12). Median total nitrogen in the HFW outflow Tanks was 1.0 and 5.5 g m^{-3}, equating to 98% and 91% reductions from the Inflow Header Tank. A few more elevated values for nitrogen were noted at the HFW East 2 outlet early in the monitoring programme.

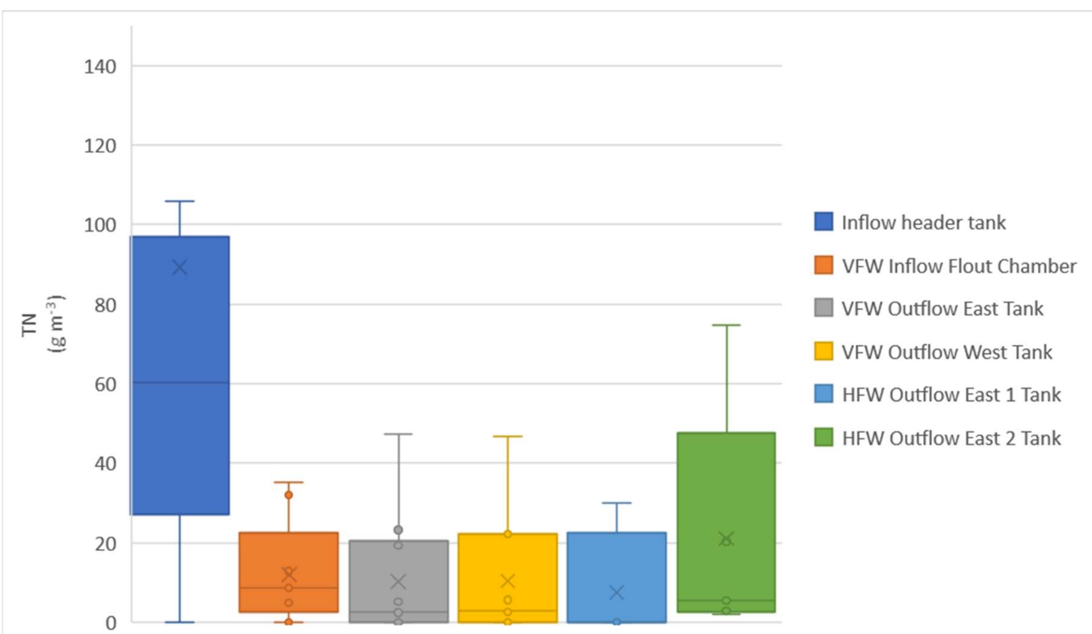


Figure 5-12: Box and whisker plot of total nitrogen concentrations in Votua constructed wetland. See Appendix A, Figure A 1 for explanation of box and whisker graph format.

Phosphorus

The median TP (Figure 5-13) in the Inflow Header Tank was 8.5 g m^{-3}, of which 1.48 g m^{-3} was Reactive Dissolved Phosphorus (RDP, Figure 5-14). The median TP had reduced to 2.62 g m^{-3} in the Inflow Flout Chamber. A further reduction to 1.32 g m^{-3} was recorded in the VFW West Tank, whereas a slight increase to 1.60 g m^{-3} occurred in the VFW East Tank. The median values in the HFW Tanks were 1.01 g m^{-3} and 1.30 g m^{-3} respectively, equating to reductions of 88% and 85% from the Inflow Header Tank.

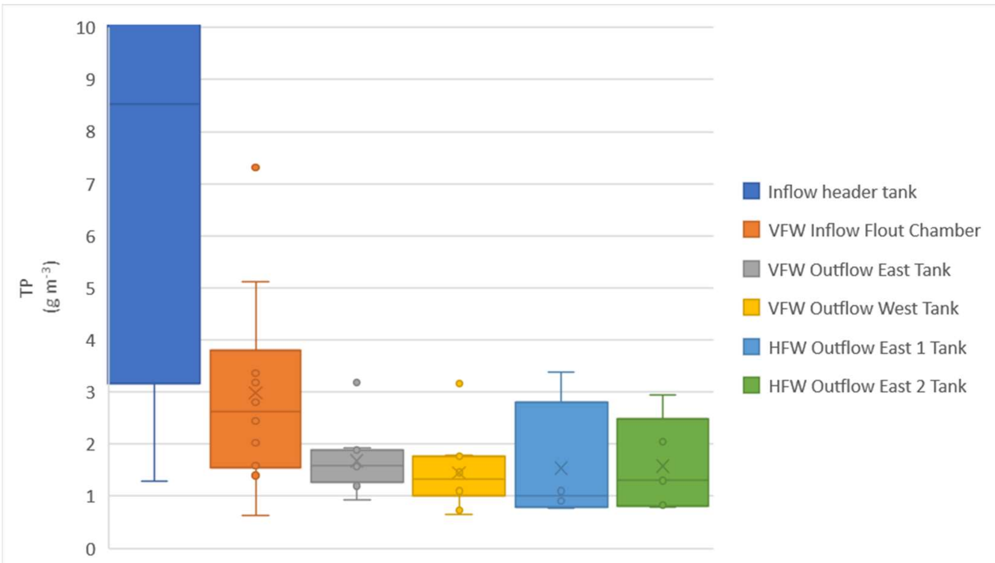


Figure 5-13: Box and whisker plot of total phosphorus in Votua constructed wetland. See Appendix A, Figure A 1 for explanation of box and whisker graph format.

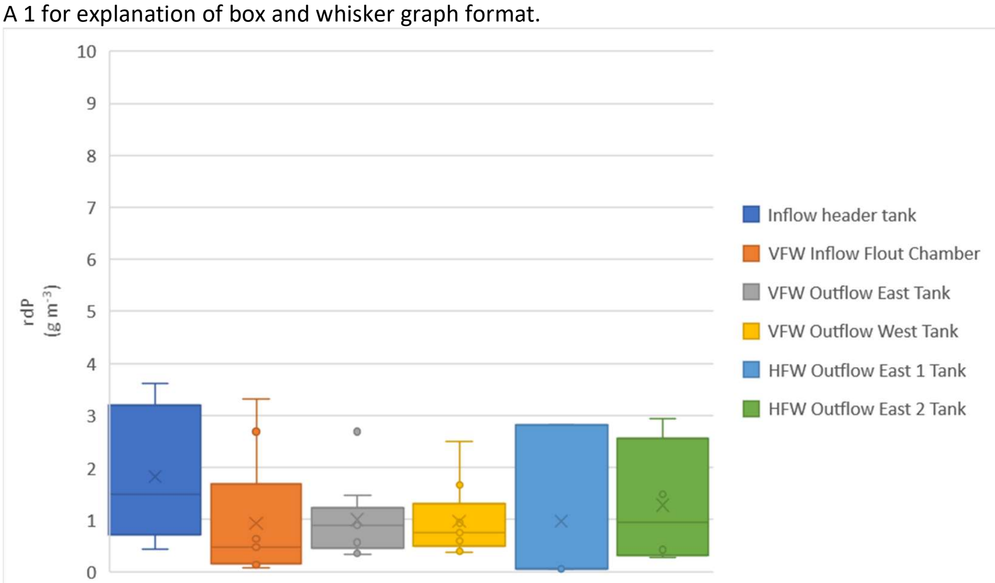


Figure 5-14: Box and whisker plot of reactive dissolved phosphorus in Votua constructed wetland. See Appendix A, Figure A 1 for explanation of box and whisker graph format

Faecal microbiological indicators

The median *E. coli* in the Inflow Header Tank was 5,450 cfu 100 mL^{-1}, with a maximum of 3,500,000 cfu 100 mL^{-1} recorded (Figure 5-15). Reductions in *E. coli* numbers were recorded through each stage of the system until the HFWs. By this stage, concentrations were at or below the laboratory detection limit of 100 cfu 100 mL^{-1}, thus no further reductions were able to be measured. Overall reductions were close to two orders of magnitude, and maximum values had reduced by over four orders of magnitude.

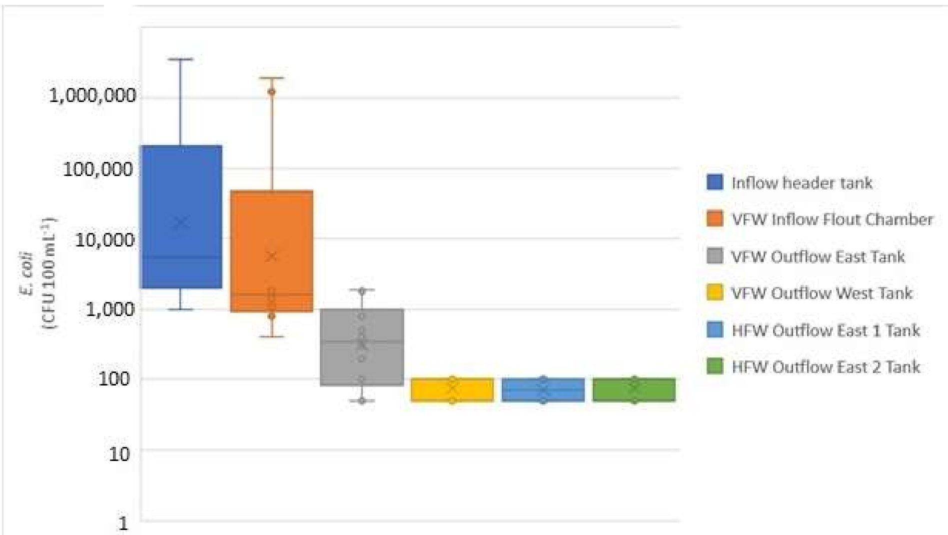


Figure 5-15: Box and whisker plot of *E. coli* in Votua constructed wetland. Note Log scale on y-axis**.**See Appendix A, Figure A 1 for explanation of box and whisker graph format.

5.4 Constructed wetland discussion

Although each wetland bed was lined with compacted clay during construction and water tested before filling with media, cracking of the clay occurred during subsequent dry periods (i.e., droughts when water use was severely restricted and when there was no power to the pump for periods). This meant that significant infiltration losses then occurred through the base of the vertical and horizontal-flow constructed wetlands. Combined seepage losses resulted in the constructed wetlands rarely discharging to the final land application stage of the treatment. Given the high level of treatment achieved in the vertical flow wetlands (see below) and the absence of any downslope groundwater wells or bores, these unplanned seepage losses to groundwater are very unlikely to have resulted in any environmental or human health risks.

The median vertical-flow wetland effluent quality was typical of advanced secondary treatment with nutrient reduction (Table 29, Auckland Council, 2018), except for BOD_5 which was more typical of secondary treatment[5]. The measured effluent quality met the A+ benchmark for on-site effluent systems in New Zealand (OSET, 2018, Appendix F) for total suspended solids, and both total and ammonium nitrogen. It at least met the B benchmark for *E. coli* (just outside the A benchmark) and for BOD_5 (<20 g m^{-3}; again limited by the laboratory detection limit of <18 g m^{-3}).

In comparison to effluent standards proposed for municipal effluent discharges in Fiji (Appendix G), median concentrations in the vertical-flow wetland (based on pooling of results from the east and west cells) met suspended solids, BOD_5, ammonium and total nitrogen and total phosphorus standards proposed for significant ecological zones in Fiji (DoE, 2007). Faecal coliform concentrations were more variable, with median *E. coli* concentrations within the standards proposed for general waters (assuming the indicative USEPA ratio of 126 *E. coli* per 200 faecal coliforms; as outlined in MfE/MoH, 2003). From the data available, there appears to be only one parameter that the Votua wetland system would not meet in the DoE standards, and that is pH, where the standard for General discharge, or discharge to a significant ecological zone is the range 7-9, whereas the median concentrations for the wetland cells were 6.4 and 6.6, while the header tank had a pH of 7.5. This slight lowering of pH is likely due to nitrification of ammonia-N in the wetlands, which consumes some alkalinity, resulting in a lower pH (Ahn, 2006, Sharma and Ahlert, 1977). It should be noted that very few, if any, other municipal, resort or industrial wastewater discharges anywhere in Fiji are likely to currently achieve the National Liquid Waste Standards (ADB, 2006).

[5] Note that apparent BOD performance was limited somewhat by the USP IAS laboratory detection limit of <18 g m^{-3},

6 Overall Summary

The primary objective of sanitation is to protect people from exposure to disease-causing substances in excreta and their transmission through drinking water supplies and the environment. The second is to reduce pollution of the surrounding environment, which can impact directly and indirectly on the well-being of local communities and the ecosystems on which they depend. The focus of this study was on the treatment performance of a range of on-site and decentralised wastewater treatment technologies applied in iTaukei Fijian villages. These systems are described in the KoroSan guidelines (Dakers et al. 2017a-e, Dakers et al. 2020 a,b). Key components of the different treatment systems were monitored in three villages. These included: dual-pit ecoVIP latrines at Namaqumaqua and Bavu, blackwater septic tanks in Votua and Namaqumaqua, land application systems in sandy and clay soils at Namaqumaqua, and a village-scale septic tank and constructed wetland system at Votua.

EcoVIP2

The ventilated improved pit latrines (ecoVIP2) are waterless toilets designed to reduce odours and enhance decomposition of accumulating faecal sludge. Each latrine incorporates two separate pits with a movable toilet pedestal which can be switched between the pits when one becomes full. The ecoVIP2 latrines were operated for 4 years at one site and 5 years at another. Odours did not cause problems to users and conditions within the accumulating faecal sludge were suitable for colonisation by invertebrate fauna that assist with its breakdown and stabilisation. Pile depth ranged from 0.2 m yr^{-1} for normal household use to 0.5 m yr^{-1} for a more intensively used system. The pile depth at the site subject to intensive use[6] had reached the point where the toilet pedestal needed be moved to the reserve pit after 4 years. These results and our consultation with users suggest ecoVIP2 toilets can provide an effective and pleasant water-less sanitation option for Fijian villages. Further studies of the subsequent decomposition rate and volume reduction in the rested pit, and characteristics of the resultant biosolids (including pathogen status) are warranted to guide safe use or disposal. This information will help understand the longer-term sustainability and cost effectiveness of ecoVIP2 toilets.

Septic Tanks

Septic tanks retain wastewaters for a day or more to allow for settling of suspended solids (forming faecal sludge), retention of floatables (forming surface scums), and their partial anaerobic biodegradation and mineralisation. The blackwater septic tanks monitored in two villages conformed to Australian and New Zealand Standards (AS/NZS 1547:2012 and outlined in KoroSan Guideline #3). They received toilet wastewaters. These septic tanks (as specified in KoroSan Guideline #3) are larger than have previously prescribed in Fiji and have effluent filters fitted to reduce discharge of suspended solids. Effluent quality assessed for 9 dual chamber septic tanks treating toilet blackwaters in 2 Fijian villages was generally stronger than reported for septic tanks elsewhere treating combined black and greywaters, but similar to that reported for blackwater septic tanks on the Gold Coast of Australia under subtropical conditions. The elevated contaminant levels found in blackwater septic tank discharges in the present study, particularly for ammonium-N, nitrogen, phosphorus and faecal indicator bacteria, show that they pose a significant potential risk to human and ecosystem health if not properly managed. Such discharges also have a high potential to clog soak pits and soil infiltration systems and contaminate groundwaters. Rates of faecal solids decomposition in the blackwater septic tanks were rapid with low rates of sludge and scum

[6] The site received wastes from a household and an adjacent Mataqali (village clan) meeting house.

accumulation. These larger tanks should function for extended periods (≥ 10 years) without the need for de-sludging under Fijian climatic conditions. This has significant advantages where the infrastructure for safe sludge removal is poorly developed.

Land Application Systems

The household land application systems tested consisted of sand infiltration trenches receiving pulsed flows of blackwater septic tank effluent. The sites chosen for the infiltration trenches were in contrasting sandy and clay soils. The trench on the sandy soil was constructed below ground utilising the existing sand subsoil. The trench on the clay soil was covered with a 400 mm deep layer of coarse coral sand laid over a drainage layer of coarse coral wrack (known locally as laselase). Both systems were covered to protect users from contact with wastewater. Pulse dosing was achieved by use of a small flout (floating outlet) chamber.

The land application systems reduced TSS by between 75% and 90% with median effluent concentrations in the base of the systems ranging between 9 g m^{-3} and 26 g m^{-3}. These would currently meet Fijian DoE (2007) standards for discharge to a significant ecological zone for this parameter (30 g m^{-3}), although at both sites, substantial further treatment would likely occur as effluent infiltrates through the subsoil beneath the land application system. Similar reductions were noted for BOD_5, with reductions of 71% and >81%, resulting in median effluent concentrations of <18 - 22 g m^{-3}. The median DoE standard for BOD_5 for general discharge is 40 g m^{-3}, thus both systems would readily achieve this standard.

TP in the land application systems reduced by between 81% and 94%, resulting in median effluent concentrations between 1.7 g m^{-3} and 4.7 g m^{-3}. These would meet DoE standards for General discharge (5 g m^{-3}) but would not routinely meet the standard for discharge to a Sensitive Ecological Zone (2 g m^{-3}).

TN in the land application systems was reduced by 74% and 92%, resulting in median effluent concentrations between 18.4 g m^{-3} and 50 g m^{-3}. The DoE standard for general discharge is 25 g m^{-3}, thus these systems would not meet this standard in all instances and would routinely fail to meet the standard for direct discharge to a Significant Ecological Zone. However, the land application systems were highly effective at reducing ammonia-N[7], with reductions >99%, achieved median effluent concentrations of 1.0 g m^{-3} and less, with some trench areas achieving a median concentration of 0.09 g m^{-3}. Both trench systems readily met the DoE standard for ammonia-N discharge to a Significant Ecological Zone of 5 g m^{-3}.

The land application systems reduced *E. coli* numbers by between 2.0 and 2.5 orders of magnitude. However effluent concentrations still ranged between 11,100 and 50,900 cfu 100 mL^{-1}, and thus would require further treatment before being suitable for direct discharge. Soil infiltration is the most appropriate means of safely returning these treated wastewaters into the environment, providing significant additional filtering and treatment.

The land application systems installed (in accord with KoroSan guideline 4) showed themselves to be able to readily treat blackwater septic tank effluents over an extended period. Reduction of suspended solids, organic matter (BOD) and nutrients provides for sustainable long-term soil infiltration providing for significant additional filtering and treatment before entering ground and

[7] Ammonia is potentially the most toxic form of dissolved N present in sewage wastewaters.

surface waters. This reduces the risk of failure of soil absorption systems and the subsequent potential for human exposure, whilst reducing the environmental impacts of village wastewater discharges.

Village septic tank and wetland system

The village-scale constructed wetland system at Votua treats the blackwater septic tank effluent from around 50 houses with a population of nearly 300 people. The wetland system consists of an initial vertical flow wetland, followed by four horizontal flow wetlands (operated in parallel) and then an infiltration garden. Due to infiltration losses through the base of the wetlands they discharged only rarely and effluent was only able to be sampled in the latter stages when present.

The wetland system routinely achieved high treatment levels, even by the end of the first vertical-flow stage. Effluent from the horizontal flow wetlands had median TSS concentrations of 5 g m^{-3} and 7 g m^{-3}. BOD_5 median effluent concentrations were below the laboratory detection limit of 18 g m^{-3} after the vertical flow wetland (>80% removal).

The vertical flow wetland was effective in achieving a high degree of nitrification (conversion of ammonium-N to nitrate-N) and reduction in overall TN concentrations. TP concentrations were also substantially reduced throughout the system.

Based on the available data, the two final treatment stages (horizontal-flow wetland and infiltration garden) constructed after the vertical flow wetland could be considered superfluous. The monitoring data shows the vertical-flow wetland effluent was highly amenable to safe and sustainable soil infiltration and would potentially also be suitable for discharge to surface waters with suitable mixing and dilution. This suggests there is potential for application of smaller, more cost-effective constructed wetlands.

Overall, these results show that all three village treatment options monitored operated effectively during the extended period of this study, providing the levels of treatment expected. This provides evidence for the acceptability of these KoroSan eco-technologies under realistic village operating conditions.

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Appendix A Understanding box and whisker plots

Effluent quality results have been presented as box and whisker plots in much of the report. The box represents the 75th and 25th percentile values and show the interquartile range (IQR). The median (50th percentile) is shown by the cross bar while the mean is shown as an X. Data points are shown as circles. The whiskers show the highest and lowest "connected" data point, defined as the highest and lowest points within 1.5 x IQR. Points outside of this are considered outlier.

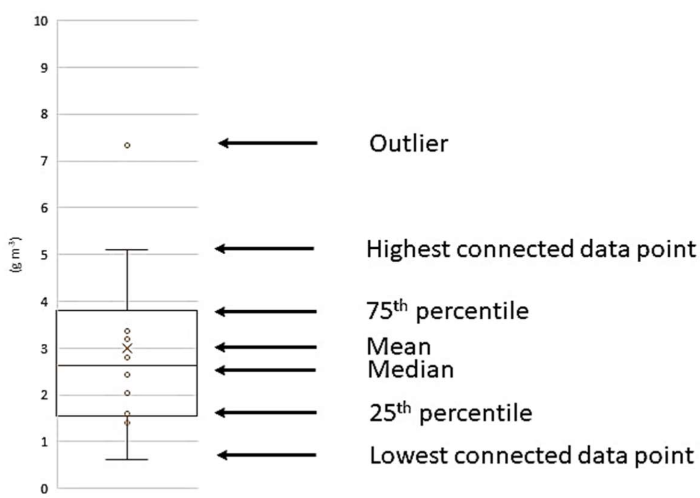

Figure A-1: Box and whisker graph explanation.

Appendix B Namaqumaqua and Bavu ecoVIP2 pit latrine data

Namaqumaqua								
	E. coli	ASH	Moisture	pH	Organic Matter	N-NH_4	Organic Nitrogen	C:N Ratio
	cfu 100 mL^{-1}	g 100 g^{-1} (%)	g 100 g^{-1} (%)	units	%	g m^{-3}	%	
Median	34,000,000	38.3	65.7	7.3	61.7	58.2	2.7	12.5
Mean *(Geomean)*	*37,669,215*	42.0	62.0	7.3	58.0	51.2	2.1	16.7
7/07/2017	920,000	36.5	75.1	7.2	63.5	NA	NA	NA
27/07/2017	34,000,000	42.1	65.7	7.0	57.9	NA	NA	NA
10/08/2017	350,000,000	34.5	62.5	7.3	65.5	NA	NA	NA
31/08/2017	240,000	62.2	69.4	7.5	37.8	NA	NA	NA
1/11/2017	16,000,000	38.3	33.4	7.3	61.7	24.3	2.7	11.4
23/12/2017	1,600,000,000	47.7	62.2	7.1	52.3	71.2	1.0	26.2
20/01/2018	1,600,000,000	32.6	65.8	7.6	67.4	58.2	2.7	12.5

Bavu								
	E. coli	ASH	Moisture	pH	Organic Matter	$N\text{-}NH_4$	Organic Nitrogen	C:N Ratio
	cfu 100 mL^{-1}	g 100 g^{-1} (%)	g 100 g^{-1} (%)	units	%	g m^{-3}	%	
Median	620,000	44.7	56.1	7.2	55.3	68.8	NA	NA
Mean *(Geomean)*	*302,848*	44.7	54.6	7.2	55.3	130.1	NA	NA
7/07/2017	1,600,000,000	40.2	77.1	7.5	59.8	NA	NA	NA
27/07/2017	200	48.2	56.4	7.3	51.8	NA	NA	NA
10/08/2017	3,300	45.0	55.9	7.1	55.0	NA	NA	NA
31/08/2017	49,000	45.2	29.8	7.0	54.8	263	NA	NA
1/11/2017	2,400,000	44.4	53.4	7.1	55.6	NA	NA	NA
22/11/2017	1,100,000	47.8	56.3	7.4	52.2	NA	NA	NA
23/12/2017	3,700,000	43.2	43.7	7.2	56.8	68.8	NA	NA
20/01/2018	140,000	43.8	63.8	7.0	56.2	58.6	1.4	20.1

Appendix C Votua and Namaqumaqua septic tank effluent quality

Votua and Namaqumaqua Septic Tank Effluent Data											
	SITE	TSS	BOD_5	$N\text{-}NH_4$	TKN	RDP	TP	FC	*E. coli*	Cond.	pH
		$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	cfu $100mL^{-1}$	cfu $100mL^{-1}$	µS	
Mean		148	102	179	197	28	25.1	1.31E+06	5.81E+06	1817	7.2
Median		78	77	193	194	23	26.3	1.30E+06	2.76E+06	1489	7.1
Geometric mean								7.05E+05	2.20E+06		
2007 - May	House 1 Votua	50	169	130	136	12.6	13.7	9.00E+05	9.00E+05	1489	7.6
	House 2 Votua	215	363	309	341	33.1	30.6	1.60E+06	1.60E+06	3340	7.1
2007 - Nov	House 1 Votua	418	218	243	294	99.8	NA	2.80E+06	2.20E+05	2710	7.1
	House 3 Votua	23	58	193	147	37.9	NA	3.40E+05	3.40E+05	1464	7.2
	House 4 Votua	729	65	133	219	54.3	NA	2.20E+06	1.30E+06	2150	7.1
	House 5 Votua	9	64	43.1	45.9	11.3	NA	1.30E+06	7.90E+05	597	6.7
	Votua community hall	42	58	76.3	85.1	24	NA	2.20E+04	4.00E+04	967	7.4
2016 - Aug	House 1 NQMQ	8	9	220	233.9	1.5	22.9	NA	7.60E+06	NA	NA
	House 2 NQMQ	104	9	156	165	13.2	17	NA	3.77E+07	NA	NA
2016 - Oct	House 1 NQMQ	44	116	NA	269	23.3	30.1	NA	8.32E+06	NA	NA
	House 2 NQMQ	81	82	NA	186	16.2	19.3	NA	2.40E+06	NA	NA
2017 - Nov (first sampling)	House 1 NQMQ	303	122	213	234	23.2	26.6	NA	8.33E+06	NA	NA
	House 2 NQMQ	143	107	143	143	21.4	26.0	NA	3.96E+06	NA	NA
2017 - Nov (second sampling)	House 1 NQMQ	78	77	225	250	25.3	29.0	NA	9.77E+06	NA	NA
	House 2 NQMQ	136	66	193	192	21.6	25.2	NA	3.00E+06	NA	NA
2017 - Nov (third sampling)	House 1 NQMQ	57	97	210	216	22.4	32.3	NA	9.80E+06	NA	NA
	House 2 NQMQ	77	46	196	194	27.9	27.9	NA	2.76E+06	NA	NA

Note: Reactive Dissolved Phosphorus (RDP) mean and median values are higher than total phosphorus (TP) values because total phosphorus was only analysed during the May 2007 sampling. The November 2007 sampling values appear generally higher, and total phosphorus values would also have been higher if they had been analysed. NQMQ = Namaqumaqua

Appendix D Namaqumaqua Land Application System data

House 1: Seaward sandy soil

Septic Tank											
	TSS	BOD_5	TP	RDP	TN	TKN	NH4-N	Organic N	NO_2-N	NO_3-N	*E. coli*
	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	cfu $100mL^{-1}$
Mean	98	84	28.2	19.1	241	241	217	16	0.14	0.18	8.76E+06
Median	57	97	29.0	23.2	235	234	217	17	0.14	0.18	8.33E+06
23/08/2016	8	9	22.9	1.48	234	234	220	14	0.05	0.06	7.60E+06
5/10/2016	44	116	30.1	23.3	270	269	NA	NA	0.22	0.29	8.32E+06
28/11/2017	303	122	26.6	23.2	235	234	213	21	NA	NA	8.33E+06
29/11/2017	78	77	29.0	25.3	251	250	225	25	NA	NA	9.77E+06
30/11/2017	57	97	32.3	22.4	216	216	210	6	NA	NA	9.80E+06

Trench A											
	TSS	BOD_5	TP	RDP	TN	TKN	NH4-N	Organic N	NO_2-N	NO_3-N	*E. coli*
	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	cfu $100mL^{-1}$
Mean	9.6	17.8	3.23	2.55	103	14.1	1.87	15.7	0.08	219.5	3.23E+04
Median	9	22	3.13	2.64	18.9	15.7	1.00	15.7	0.08	219.5	2.92E+04
% removal Mean	90%	79%	89%	87%	57%	94%	99%	5%			
% removal median	84%	77%	89%	89%	92%	93%	99.5%	10%			
23/08/2016	9	22	3.13	2.65	177	15.7	0.01	15.7	0.07	161	6.20E+04
5/10/2016	15	9	2.73	2.64	296	17.7	NA		0.09	278	1.91E+04
28/11/2017	16	22	4.30	4.30	16.5	15.6	0.86	14.7	NA	NA	2.18E+04
29/11/2017	4	27	2.09	1.75	18.9	17.8	1.13	16.7	NA	NA	2.92E+04
30/11/2017	4	9	3.92	1.40	9.02	3.55	5.47		NA	NA	2.98E+04

Trench B											
	TSS	BOD_5	TP	RDP	TN	TKN	NH4-N	Organic N	NO_2-N	NO_3-N	*E. coli*
	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	cfu $100mL^{-1}$
Mean	23.9	20	2.01	0.99	57.2	12.7	1.14	9.35	0.135	110.6	8.46E+04
Median	13	9	1.68	0.85	18.4	12.8	0.79	9.17	0.135	110.6	5.09E+04
% removal Mean	76%	76%	93%	95%	76%	95%	99%	43%			
% removal median	77%	>81%	94%	96%	92%	95%	99.6%	47%			
23/08/2016	0.5	36	1.68	1.00	85.4	8.53	2.64	5.89	0.12	74.1	5.52E+04
5/10/2016	6	9	0.46	0.25	165	21.3	NA	NA	0.15	147	5.09E+04
28/11/2017	13	9	3.33	2.05	13.2	12.8	0.36	12.44	NA	NA	2.54E+05
29/11/2017	31	36	1.43	0.85	18.4	17.8	0.57	17.23	NA	NA	2.66E+04
30/11/2017	69	9	3.13	0.78	3.8	2.84	1.00	1.84	NA	NA	3.59E+04

House 2: Landward clay soil

Septic Tank											
	TSS	BOD_5	TP	RDP	TN	TKN	NH4-N	Organic N	NO_2-N	NO_3-N	*E. coli*
	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	cfu $100mL^{-1}$
Mean	108	62	23.1	20.1	186	176	172	9	0.08	0.15	9.96E+06
Median	104	66	25.2	21.4	191	186	175	9	0.08	0.15	3.00E+06
23/08/2016	104	9	17	13.2	165	165	156	9	0.08	0.11	3.77E+07
5/10/2016	81	82	19.3	16.2	186	186	NA	NA	0.09	0.18	2.40E+06
28/11/2017	143	107	26	21.4	191	143	143	NA	NA	NA	3.96E+06
29/11/2017	136	66	25.2	21.6	193	192	193	NA	NA	NA	3.00E+06
30/11/2017	77	46	27.9	27.9	196	194	196	NA	NA	NA	2.76E+06

Trench A											
	TSS	BOD_5	TP	RDP	TN	TKN	NH4-N	Organic N	NO_2-N	NO_3-N	*E. coli*
	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	cfu $100mL^{-1}$
Mean	23	20	2.79	1.37	33.7	21.7	0.300	12.4	3.06	26.9	6.75E+05
Median	26	19	2.68	1.13	26	12.1	0.085	11.4	3.06	26.9	1.11E+04
% removal Mean	79%	68%	88%	93%	82%	88%	99.8%	-38%			
% removal median	75%	71%	89%	95%	86%	93%	99.95%	-27%			
23/08/2016	28	9	2.32	1.13	63	12.1	0.01	12.1	0.02	51	2.91E+06
5/10/2016	46	29	4.22	2.74	66	57.6	NA		6.1	2.7	4.43E+05
28/11/2017	26	19	2.68	1.13	26	26	1.02	25.0	NA	NA	8.20E+03
29/11/2017	6	9	1.51	0.09	10.7	10.7	0.009	10.7	NA	NA	7.73E+03
30/11/2017	9	33	3.24	1.74	2.13	2.13	0.16	2.0	NA	NA	1.11E+04

Trench B											
	TSS	BOD_5	TP	RDP	TN	TKN	NH4-N	Organic N	NO_2-N	NO_3-N	*E. coli*
	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	cfu $100mL^{-1}$
Mean	22.1	11.8	4.68	3.0	49.6	12.8	0.11	9.7	2.56	27.9	3.48E+05
Median	10	9	4.71	3.7	49.6	13.5	0.09	11.6	2.56	27.9	1.63E+04
% removal Mean	80%	81%	80%	85%	73%	93%	99.9%	-8%			
% removal median	90%	>73%	81%	83%	74%	93%	99.9%	-29%			
23/08/2016	27	9	4.52	3.7	58.4	13.5	0.07	13.43	0.22	44.7	1.17E+06
5/10/2016	68	23	4.71	3.64	40.7	24.8	NA		4.9	11	5.33E+05
28/11/2017	10	9	4.89	4	NA	10	0.17	9.83	NA	NA	1.63E+04
29/11/2017	5	9	4.4	0.11	NA	13.5	0.11	13.39	NA	NA	7.70E+03
30/11/2017	0.5	9	4.9	3.76	NA	2.13	0.07	2.06	NA	NA	1.17E+04

Appendix E Votua Constructed Wetland Data

Header tank inflow

	Temp	DO	pH	EC	TSS	BOD_5	NO_2-N	NO_3-N	NH_4-N	TKN	Organic-N	TN	RDP	TP	*E. coli*
	°C	%	pH units	mS cm^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	cfu 100 ml^{-1}
Median	26.3	45.7	7.5	472	229	45	0.20	0.77	18.7	45.2	25.0	60.3	1.48	8.5	5,450
Mean	26.8	34.4	7.5	527	2,579	98	0.39	0.71	22.8	82.0	65.9	89.4	1.82	15.2	399,390
Maximum	30.1	55.5	7.7	725	16,570	528	1.13	0.93	54.0	421.0	400.9	421.0	3.62	64.2	3,500,000
Minimum	25.3	2.5	7.2	432	6	24	0.04	0.29	0.01	0.01	0.01	0.01	0.43	1.29	1,000
25/08/2016	25.3	5.47	7.7	466	8	<18	1.13	0.90	30.4	30.4	0.0	32.4	2.80	3.37	230,000
29/08/2016	27.5	55.5	7.5	443	6	24	0.25	0.93	33.4	33.4	0.0	34.6	3.62	3.40	200,000
7/12/2016	25.6	29.7	7.6	699	19	<18	0.14	0.93	54.0	54.0	0.0	55.1	NA	5.64	3,500,000
7/05/2017	26.1	47.9	7.3	497	420	65	0.04	0.29	17.3	65.1	47.8	65.4	1.99	11.4	6,300
27/05/2017	30.1	54.6	7.2	725	6,510	104	0.64	0.57	12.9	92.7	79.8	93.9	0.99	32.9	2,300
10/08/2017	28.7	49.4	7.7	638	366	81	0.12	0.64	13.7	72.1	58.4	72.9	1.48	12.3	3,300
31/08/2017	25.4	43.5	7.3	478	16,570	528	NA	NA	20.1	421	400.9	421	1.06	64.2	4,600
1/11/2017	27.6	2.54	7.3	450	1,785	143	NA	NA	37.1	106	68.9	106	3.58	15.3	45,000
22/12/2017	26.5	51.7	7.4	437	18	<18	NA	NA	0.01	<2	1.0	<2	0.44	2.56	1,400
23/12/2017	25.5	4.02	7.5	432	92	<18	NA	NA	9.28	11.4	2.1	11.4	0.43	1.29	1,000

Censored values (<) have been replaced with half the detection value to calculate means

VFW Inflow Flout Chamber															
	Temp	DO	pH	EC	TSS	BOD_5	NO_2-N	NO_3-N	NH_4-N	TKN	Organic-N	TN	RDP	TP	*E. coli*
	°C	%	pH units	mS cm^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	cfu 100 ml^{-1}
Median	26.4	37.6	7.7	419	67	<18	0.13	0.20	0.14	6.78	4.5	8.6	0.47	2.62	1,600
Mean	27.0	36.9	7.6	396	113	15	0.22	2.08	7.28	8.19	4.1	12.2	0.93	2.99	345,422
Maximum	29.4	52.8	7.9	488	381	35	0.63	8.95	33.9	33.9	8.7	35.3	3.32	7.32	1,900,000
Minimum	24.5	19.4	7.4	265	2	<18	0.01	0.09	0.03	<2	0	<2	0.08	0.62	400
% Change median from header tank inflow				-11%	-71%	-80%	-33%	-74%	-99%	-85%	-82%	-0.9	-68%	-69%	-71%
% Change mean from header tank inflow				-25%	-96%	-85%	-44%	194%	-68%	-90%	-94%	-0.9	-49%	-80%	-14%
25/08/2016	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.69	3.19	NA
29/08/2016	28.3	40.1	7.8	458	2	35	0.31	1.07	33.9	33.9	0.0	35.3	3.32	3.36	1,200,000
7/12/2016	24.5	37.6	7.7	488	8	<18	0.63	8.95	22.4	NA		32.0		5.11	1,900,000
7/05/2017	26.7	39.6	7.9	416	356	<18	0.01	0.20	0.03	8.75	8.7	9.0	0.18	2.44	1,700
27/05/2017	29.4	52.8	7.4	375	5	<18	0.13	0.09	0.07	4.99	4.9	5.2	0.08	1.59	1,800
10/08/2017	29.0	51.8	7.4	420	67	26	0.01	0.11	0.03	<2	1.0	<2	0.13	0.62	1,600
31/08/2017	26.2	34.7	7.7	447	381	<18	NA	NA	0.21	8.56	8.4	8.6	0.21	2.80	1,100
1/11/2017	26.3	19.4	7.6	419	110	18	NA	NA	0.08	4.99	4.9	5.0	0.67	2.03	1,400
22/12/2017	26.4	29.9	7.5	272	76	<18	NA	NA	8.62	12.8	4.2	12.8	0.63	7.32	800
23/12/2017	26.2	26.6	7.8	265	14	<18	NA	NA	0.14	<2	1.0	<2	0.47	1.40	400

VFW Outflow East Tank

	Temp	DO	pH	EC	TSS	BOD_5	NO_2-N*	NO_3-N*	NH_4-N	TKN	Organic-N	TN	RDP	TP	*E. coli*
	°C	%	pH units	mS cm^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	cfu 100 ml^{-1}
Median	26.5	42.9	6.7	197	4	<18	0.06	7.2	0.1	1.0	1.0	3.7	0.89	1.60	350
Mean	26.8	43.8	6.6	193	4	11	0.20	12.7	1.8	3.1	1.2	10.7	0.99	1.68	610#
Maximum	29.8	53.4	7.4	428	13	24	0.78	39.3	10.9	10.9	3.6	47.2	2.69	3.19	1,900
Minimum	24.8	35.8	5.8	66	<1	<18	0.01	1.23	<0.007	1.4	0	1.4	0.34	0.93	100
% Change median from VFW inflow				-53%	-94%	0%	-54%	3490%	-39%	-85%	-78%	-57%	89%	-39%	-78%
% Change mean from VFW inflow				-51%	-96%	-29%	-8%	511%	-75%	-62%	-70%	-13%	7%	-44%	-100%
% Change median from header tank inflow				-58%	-98%	-80%	-69%	832%	-100%	-98%	-96%	-94%	-40%	-81%	-94%
% Change mean from header tank inflow				-63%	-100%	-89%	-48%	1694%	-92%	-96%	-98%	-88%	-45%	-89%	-100%
25/08/2016	25.4	53.4	6.5	317	<1	<18	0.78	11.5	10.9	10.9	0	23.2	2.69	3.19	1,900
29/08/2016	27.0	48.5	6.9	428	2	24	0.1	39.3	4.2	7.79	3.59	47.2	1.46	1.57	800
7/12/2016	24.8	39.5	5.9	213	5	<18	0.02	19.1	0.29	NA	NA	19.4		0.93	1,800
7/05/2017	26.9	51.2	7.3	121	4	<18	0.02	2.86	0.03	<2	1	2.9	0.65	1.63	100
27/05/2017	29.8	38.5	7.4	221	13	<18	0.27	1.23	2.56	3.57	1.01	5.1	1.01	1.92	400
10/08/2017	29.4	45.8	6.8	230	2	<18	0.01	2.42	0.02	<2	1	2.5	1.00	1.20	300
31/08/2017	25.8	38.0	7.0	180	4	<18	NA	NA	0.01	<2	1	<2	0.56	1.29	500
1/11/2017	27.0	35.8	6.2	80.9	5	<18	NA	NA	<0.007	1.43	1.43	1.4	0.35	1.88	<100
22/12/2017	26.1	47.4	5.8	65.7	<1	<18	NA	NA	0.14	<2	1	<2	0.89	1.62	200
23/12/2017	25.3	39.9	6.2	75.1	6	<18	NA	NA	0.03	<2	1	<2	0.34	1.56	<100

*Note that concentrations of TN substantially reduced throughout the study period. This would also have occurred for nitrate-N and nitrite-N. However, as they were not analysed for the final 4 sampling occasions, median and mean values for nitrate-N exceed those for total nitrogen.

Censored values (<) have been replaced with half the detection value to calculate means

VFW Outflow West Tank															
	Temp	DO	pH	EC	TSS	BOD_5	NO_2-N*	NO_3-N*	NH_4-N	TKN	Organic-	TN	RDP	TP	*E. coli*
	°C	%	pH units	mS cm^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	cfu 100 ml^{-1}
Median	26.2	45.9	6.6	188	3	<18	0.19	8.3	0.02	<2	1.0	3.8	0.75	1.32	100
Mean	52.4	47.6	6.7	192	10	<18	0.29	13.5	1.98	2	0.8	11.0	0.96	1.45	80#
Maximum	29.1	76.1	7.4	403	66	<18	0.89	37.3	10.60	11	1.4	46.8	2.50	3.17	100
Minimum	25.1	37.2	6.0	72	1	<18	0.02	2.57	0.01	<2	0	1.4	0.37	0.64	<100
% Change median from VFW inflow				-55%	-96%	0%	42%	4045%	-86%	-85%	-78%	-0.6	60%	-50%	-94%
% Change mean from VFW inflow				-51%	-91%	-39%	35%	550%	-73%	-70%	-80%	-0.1	4%	-51%	-100%
% Change median from header				-60%	-99%	-80%	-5%	977%	-100%	-98%	-96%	-0.9	-49%	-85%	-98%
% Change mean from header tank				-64%	-100%	-91%	-24%	1807%	-91%	-97%	-99%	-0.9	-47%	-90%	-100%
25/08/2016	25.8	76.1	6.5	324	14	<18	0.89	11.0	10.6	10.6	0	22.5	2.50	3.17	<100
29/08/2016	27.6	45.1	7.0	403	3	<18	0.45	37.3	9.0	9.0	0	46.8	1.66	1.77	100
7/12/2016	25.3	37.6	6.0	219	2	<18	0.03	22.1	0.04	NA	NA	22.2		0.64	<100
7/05/2017	25.4	48.7	7.2	144	66	<18	0.03	5.58	0.02	<2	1	5.6	0.59	1.18	100
27/05/2017	28.7	45.8	7.4	218	4	<18	0.34	2.68	0.06	<2	1	3.1	0.82	1.46	100
10/08/2017	29.1	42.5	6.7	225	3	<18	0.02	2.57	0.02	<2	1	2.6	0.94	1.17	100
31/08/2017	25.6	47.4	6.9	157	2	<18	NA	NA	0.02	<2	1	<2	0.75	1.1	100
1/11/2017	26.8	37.2	6.4	73.7	4	<18	NA	NA	0.01	1.43	1.42	1.4	0.66	1.48	<100
22/12/2017	26.5	46.0	6.3	72.4	1	<18	NA	NA	0.02	<2	1	<2	0.37	1.79	100
23/12/2017	25.1	49.6	6.4	85	<1	<18	NA	NA	0.02	<2	1	<2	0.39	0.73	<100

*Note that concentrations of TN substantially reduced throughout the study period. This would also have occurred for nitrate-N and nitrite-N. However as they were not analysed for the final 4 sampling occasions, median and mean values for nitrate-N exceed those for total nitrogen.

Censored values (<) have been replaced with half the detection value to calculate means

HFW Outflow East 1 Tank															
	Temp	DO	pH	EC	TSS	BOD_5	NO_2-N	NO_3-N*	NH_4-N	TKN	Organic-	TN	RDP	TP	*E. coli*
	°C	%	pH units	mS cm^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	cfu 100 ml^{-1}
Median	26.2	41.4	6.6	72	7	<18	0.05	6.7	0.1	1.0	1.0	1.0	0.05	1.01	75
Mean	26.2	46.2	6.5	141	7	<18	0.05	6.7	4.0	6.1	0.9	8.0	0.97	1.54	75#
Maximum	27.0	73.8	6.6	368	13	<18	0.05	13.4	15.8	16.4	1.0	29.9	2.81	3.38	100
Minimum	25.4	28.4	6.2	54	1	<18	0.04	0.05	0.02	<2	0.6	0.2	0.05	0.76	<100
% Change median from VFW inflow				-63%	75%	0%	-25%	-6%	-35%	0%	0%	-73%	-	-37%	-79%
% Change mean from VFW inflow				-27%	67%	-14%	-78%	-47%	119%	99%	-29%	-25%	-2%	-8%	-88%
% Change median from header				-85%	-97%	-80%	-77%	773%	-100%	-98%	-96%	-98%	-	-88%	-99%
% Change mean from header tank				-73%	-100%	-91%	-88%	847%	-83%	-93%	-99%	-91%	-	-90%	-100%
25/08/2016	26.0	73.8	6.6	368	1	<18	0.05	13.4	15.8	16.4	0.6	29.9	2.81	3.38	100
29/08/2016															
7/12/2016	25.4	28.4	6.6	85.8	NA	<18	0.04	0.05	0.07	NA	NA	0.2		0.76	100
7/05/2017															
27/05/2017															
10/08/2017															
31/08/2017															
1/11/2017															
22/12/2017	27.0	51.8	6.2	58.0	7	<18	NA	NA	0.04	<2	1	<2	0.05	0.91	<100
23/12/2017	26.4	30.9	6.5	53.6	13	<18	NA	NA	0.02	<2	1	<2	0.05	1.1	<100

*Note that concentrations of TN substantially reduced throughout the study period in preceding treatment stages. This would also have occurred for nitrate-N and nitrite-N. The median TN value is less than that for nitrate-N due to the uneven number of samples analysed.

Censored values (<) have been replaced with half the detection value to calculate means

HFW Outflow East 2 Tank															
	Temp	DO	pH	EC	TSS	BOD_5	NO_2-N	NO_3-N	NH_4-N	TKN	Organic-	TN	RDP	TP	*E. coli*
	°C	%	pH units	mS cm^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	cfu 100 ml^{-1}
Median	26.4	46.2	6.4	157	5	<18	0.04	3.45	2.0	4.6	1.0	5.5	0.96	1.30	100
Mean	26.7	42.0	6.4	191	7	12	0.11	17.4	9.6	5.7	1.2	21.1	1.28	1.58	80#
Maximum	28.6	53.4	6.8	366	16	23	0.25	48.5	26.0	26.0	2.8	74.8	2.93	2.95	100
Minimum	25.0	27.7	6.2	67	0.5	<18	0.03	0.16	0.04	2.0	0	2.1	0.28	0.79	<100
% Change median from VFW inflow				-16%	67%	0%	-78%	-58%	9850%	362%	3%	44%	27%	-2%	0%
% Change mean from VFW inflow				0%	-33%	0%	-64%	28%	387%	128%	47%	92%	33%	9%	0%
% Change median from header				-67%	-98%	-80%	-79%	348%	-89%	-90%	-96%	-91%	-	-85%	-98%
% Change mean from header tank				-64%	-100%	-91%	-72%	2346%	-58%	-93%	-98%	-76%	-	-90%	-100%
25/08/2016	26.4	53.4	6.5	284	0.5	<18	0.25	48.5	26	26	0	74.8	1.49	2.04	100
29/08/2016	28.6	46.2	6.8	366	2	23	0.04	0.16	20.1	20.1	0	20.3	2.93	2.95	100
7/12/2016	25	29.8	6.2	157	NA	<18	0.03	3.45	1.99	1.99	0	5.47	NA	0.79	100
7/05/2017															
27/05/2017															
10/08/2017															
31/08/2017															
1/11/2017															
22/12/2017	27.3	53.1	6.4	67.3	16	<18	NA	NA	0.04	2.84	2.8	2.84	0.42	0.83	<100
23/12/2017	26.3	27.7	6.3	82.6	8	<18	NA	NA	0.07	2.13	2.06	2.13	0.28	1.3	<100

Censored values (<) have been replaced with half the detection value to calculate means

Appendix F New Zealand Benchmark Rating Indicators for Onsite effluent treatment systems

Rated Indicators for Median Value unless stated otherwise	Rating Letters and Corresponding Levels				
	A+	A	B	C	D
cBOD (mg/L)	≤5	≤10	≤20	≤30	>30
TSS (mg/L)	≤5	≤10	≤20	≤30	>30
Total nitrogen (mg/L)	≤5	≤15	≤25	≤30	>30
Ammoniacal nitrogen (mg/L)	≤1	≤5	≤10	≤20	>20
Total phosphorus (mg/L)	≤1	≤2	≤5	≤7	>7
E. coli (MPN/100 ml) 90%ile	≤10	≤200	≤10,000	≤100,000	>100,000
Energy (kWh/1000 L) mean	≤1	≤2	≤3	≤5	≥5

Note: mg/L is equivalent to g m^{-3}
Source (OSET, 2018)

Appendix G Fiji wastewater effluent standards

Effluent quality parameter	Fiji (single sample)	
	General	Significant ecological zone
pH	7- 9	
TSS (g m^{-3})	60	30
BOD_5 (g m^{-3})	40	20
TN (g m^{-3})	25	10
NH_4-N (g m^{-3})	10	5
TP (g m^{-3})	5	2
Faecal coliforms (cfu 100 mL^{-1})	400	200

Source: National Liquid Waste Standards (DoE, 2007)