OXFAM UNHCR The UN Refugee Agency ARUP

Faecal Sludge Management for Disaster Relief

Technology Comparison Study

Contents

EXECUTIVE SUMMARY

On behalf of Oxfam, Arup has conducted a technical comparison study on different faecal sludge management (FSM) methods at the Rohingya camps close to Cox's Bazar (CXB), Bangladesh. The aim of the study is to draw conclusions on best practices in FSM for disaster relief from evidence gathered through practical experience. The study uses existing available data to inform the analysis, but in many cases these datasets are limited. The findings from the report should therefore be treated as provisional and relevant to the particular context in CXB.

Over 20 operational FSM sites were visited in CXB, constructed by eight different NGOs and using eight different technologies. The eight FSM technologies were:

1. **Constructed wetlands**
2. **GeoTubes**
3. **Lime (three main types: lagoons, in-barrel and three tanks)**
4. **Anaerobic lagoons**
5. **Aerobic treatment**
6. **Upflow filters (two main types; with and without pre-settlement)**
7. **Biogas**
8. **Anaerobic baffled reactors (ABR)**

The FSM technologies were compared against a set of indicators, including: cost; footprint area; speed of construction and commissioning; operation and maintenance issues; pathogen inactivation and resilience to natural disasters.

A scoring of one (most effective) to five (least effective) has been given to each technology for each indicator. For longer-term, i.e. over two years, decentralised FSM technologies, the upflow filters score well against a number of the key indicators and are therefore considered an effective ‘all round’ FSM technology. The aerobic treatment and anaerobic lagoons, both centralised treatments, scored similar. The lagoons scored slightly better as the technology is simpler to operate and maintain. Although these technologies have the lowest/best scores, they still have limitations and selection should be informed by site conditions.

In the immediate phase of an emergency, lime treatment is still considered the appropriate FSM technology choice due to its speed of setup, stability of the treatment process and effluent quality. However, due to the high operational expenditure (OPEX) of lime it is not appropriate to use it as a longer-term solution, i.e. after one or two years.

Footprint area and costs were two indicators of interest in this study. The footprint area comparison showed that the technology that provides full faecal sludge treatment and has the lowest footprint area is lime treatment.

The costs comparison includes capital expenditure (CAPEX in \$ per m^3 treated), operational expenditure (OPEX in \$ per m^3 treated) and the whole life costs (WLC in \$), which assume a 10-year life. The lowest WLC FSM plants are the decentralised upflow filters and the ABR. This is due to the low OPEX of these systems and longevity of materials used. Lime had a relatively high WLC due to the high OPEX (cost of hydrated lime). The centralised systems (biological and aeration) had relatively high CAPEX due to the size of the infrastructure, so higher WLC.

Another key finding from CXB was that adequate allowances and resources (e.g. budget, area, operational skills, etc.) should be made for the full treatment process. This must include liquid and solids management and final disposal.

Some sites visited did not have a full treatment process; this is noted in the technology review section

General view, Camp 6

1 INTRODUCTION

Arup has conducted this technical comparison study of faecal sludge management (FSM) techniques for disaster relief on behalf of Oxfam GB (Oxfam). The aim of the study is to draw conclusions on best practices in FSM for disaster relief from evidence gathered through practical experience in the Rohingya refugee camps close to Cox's Bazar, Bangladesh, referred to as CXB throughout the report.

A comparison of the FSM technologies is provided in section 4 of this report, and guidance on technology selection for future disaster relief situations is provided in section 5. Details of each FSM technology visited in CXB are given in section 6.

As part of this study, Arup visited over 20 FSM sites in CXB. These were constructed and operated by eight different NGOs and used eight different technologies. The FSM technologies reviewed are as follows:

- Constructed wetlands
- GeoTubes
- Lime (three main types: lagoons, in-barrel and three tanks)
- Anaerobic lagoons
- Aerobic treatment
- Upflow filters (two main types: with and without pre-settlement)
- Biogas plants
- Anaerobic Baffled Reactors (ABR)

The technologies have been grouped as follows, by scale and treatment mechanism:

Decentralised biological and mechanical treatment	Upflow Anaerobic Filters
	GeoTubes
	Septic/retention-tanks/ABR
Decentralised biological treatment	Constructed wetlands
	Biogas plants
Decentralised chemical treatment	Lagoon lime treatment with dewatering bed
	In-barrel lime treatment with dewatering beds
	Three-stage lime tanks
Centralised biological treatment	Anaerobic lagoons
	Aerobic treatment

2 METHODOLOGY

As noted above, eight technologies were reviewed as part of this study[1]. All sites had a minimum capacity[2] of 5 cubic metres per day.

A set of indicators, against which the site data was collected, were agreed with Oxfam ahead of the site visit. The indicators are consistent with the factors Oxfam considers when planning an FSM plant. The indicators are also in line with those used by other consultancies/NGOs during previous assessments of CXB FSM sites[3]. This ensured that the data collected by Arup was comparable. A background review was conducted to understand typical ranges for each indicator for each technology[4].

The key indicators considered are listed below, with a full list provided in Appendix A.

- **Capital expenditure and operational costs (CAPEX and OPEX);**
- **Area requirement and layout;**
- **Speed of construction and commissioning;**
- **Expertise required for setup and operation;**
- **Operation and maintenance issues;**
- **Process pinch points;**
- **Quality of liquid and solid effluent (pathogen inactivation);**
- **Disposal of final products (liquid and solid); and**
- **Resilience to flooding/natural disaster.**

(1) These differed slightly from the technologies initially identified in the Oxfam scoping document. It was later agreed with Oxfam that the study would focus on sites with a minimum plant capacity of 5m^3 per day, which dictated the final technologies reviewed.
(2) Capacity means the maximum overall capacity of the plant, i.e. the processing throughput.
(3) For example, the Octopus Case Studies and NGO factsheets as discussed and agreed with the United Nations High Commission for Refugees (UNHCR) and Octopus. See https://octopus.solidarites.org/.
(4) The majority of the FSM examples reviewed for this purpose (outside of the Rohingya refugee camps in CXB) were not from disaster relief situations (due to lack of reliable published data); however, the background study has focused on a development context. Effort was made to use unbiased and accredited sources of information; however, due to the limited practical experience with some of the technologies this was not always possible.

Indicators have been grouped under the following categories for ease of data collection:

- **Site characteristics**
  Example indicators: location, topography and proximity to groundwater.
- **Technology**
  Details about the technology used, including: scale, footprint area, layout, materials, and speed of construction.
- **Treatment process**
  Details of the treatment process used[5], including: pathogen removal mechanism and efficiency; and stability to changes in climate or influent characteristics.
- **Operation and maintenance**
  Including routine tasks, workforce required, skills required and health and safety (H&S).
- **Cost**
  Example indicators: CAPEX and OPEX
- **Environmental and social context**
  Including understanding final discharge routes, nuisance (e.g. odour) and social acceptance.

Site data was collected from participating NGOs, through site visits and site measurements, and from background information provided by Oxfam, the United Nations High Commission for Refugees (UNHCR) and Octopus[6].

From the site data collected in CXB, Arup prepared the technology comparison outlined in section 4. Arup has also reviewed the site data against the typical parameters identified in the background study to identify any outliers.

A rating system of one to five has been applied for each indicator for each technology. This gives an overview of the advantages and disadvantages of each and may help inform the selection of the most appropriate technology in a future disaster relief contexts.

(5) Several technologies may employ the same treatment process e.g. anaerobic digestion.
(6) Octopus is an online collaboration programme for FSM, operated by Solidarites International.

3 CONSTRAINTS AND ASSUMPTIONS

The report is based on information gathered from site visits, technical documents from participating organisations and a background literature study. Most of the features noted about operational FSM plants, i.e. layouts and costs, are site specific and dependent on the sludge characteristics, site constraints, location, climate, etc. Effort has been made to present the general principles to allow conclusions to be drawn from the technologies in operation in CXB.

COST

From the cost data collected, the site-specific CAPEX has been separated out to give more (geographically) transferable data. For example, in CXB a large portion of construction costs came from slope stabilisation work and geotechnical site preparation, which may not be needed in a different location. The cost of FSM plants is also difficult to transfer (geographically) due to varying costs, including for materials and labour, but it is assumed that the cost of each technology is roughly reflective.

Where FSM sites do not include the full treatment process, no extra cost (or footprint area) has been included. However, this could be undertaken as an update to this initial analysis.

OPEX has been based on data provided by the NGOs whose sites were visited. Where there are obvious oversights, such as the cost of frequent maintenance, these have been estimated and included by Arup.

Collection and transport of faecal sludge (FS) has been excluded from this study, but where they pose a constraint on the technology or treatment process, this has been noted. In most cases, the collection team also operates the FSM plant. The costs of collection have not been included in the OPEX.

Whole life cost (WLC) has been calculated to give the overall cost of operating the FSM plant for 10 years. The WLC assumes the plant operates for 10 years and includes the initial CAPEX, OPEX for 10 years and CAPEX repeats, i.e. the capital costs of items that need to be replaced within 10 years of construction. A sensitivity check with WLC set at 5, 10 and 15 years is provided in Appendix D1.

TREATMENT EFFECTIVENESS

UNHCR and UPM are currently undertaking a study on FS characteristics and effluent quality from FSM plants in CXB. The initial data from the UPM study has been used in this report to estimate the treatment efficiency. In some cases the UPM testing performed was not at the same sites as those visited by Arup but represents the same technology. There were also known issues with the processing of FS samples during the UPM study, which has affected the

data, particularly for biological oxygen demand (BOD). Additional data from NGOs' monitoring has also been considered[7].

Arup has not undertaken a detailed review of actual performance versus theoretical performance, as the focus of this study was getting real data from sites. Further analysis and review of pathogen removal could be undertaken as an update to this initial analysis.

As noted above, the characteristics of the incoming sludge have a large influence on the technology choice, treatment efficiency and the costs. A comparison of CXB sludge characteristics (from the UPM study) to typical parameters (from the wider literature) is provided in Appendix C. This has shown that CXB FS is generally within the expected range for pit latrines and septic tanks (in developing countries)[8], giving some confidence that the findings from CXB can be transferred to other geographical contexts. The site data did show that the FS in CXB has a relatively low proportion of solids, comes in high volumes and has low levels of nutrients, likely due to the low levels of cleaning products entering the wastewater.

EFFLUENT STANDARDS

Effluent quality at each site (from UPM data) was compared to the Bangladesh Department of Environment (DoE) standards for discharge to inland watercourses and the World Health Organization (WHO) 2006 'Guidelines for the Safe Use of Wastewater, Excreta and Greywater'[9]. These were considered the appropriate standards to estimate impact on environmental and public health respectively. Assessing the public health impact of technologies included considering the exposure of workers to pathogens throughout the treatment process and exposure of the public via the end products. Site-specific (and country-specific) effluent quality should be considered when selecting an FSM technology.

CENTRALISED AND DECENTRALISED

In this study, 'centralised' is taken to mean a large FSM plant, i.e. a treatment capacity of over 20m^3 per day, which serves a large area, e.g. one camp. Decentralised are smaller FSM plants serving the surrounding area, but limited in this study to a minimum capacity of 5m^3 per day. Household scale technologies have not been considered as part of this study.

Economies of scale can be achieved with centralised plants versus decentralised, e.g. one anaerobic lagoon FSM plant versus 10 lime plants. An illustration of the costs can be found in Appendix E1.

(7) Effluent sample data was provided by Solidarity International and IFRC for the GeoTubes and Aerobic Treatment respectively.
(8) CXB sludge is either discharged directly to the FSM plant from pit latrine desludging or it is stored in an intermediate tank (for a few days only) from which it is discharged to the FSM plant. These conditions are considered similar to the literature data on FS characteristics pit latrines and septic tanks.
(9) Guidelines for the Safe Use of Wastewater, Excreta and Greywater, © World Health Organization 2006

4 TECHNOLOGY COMPARISON

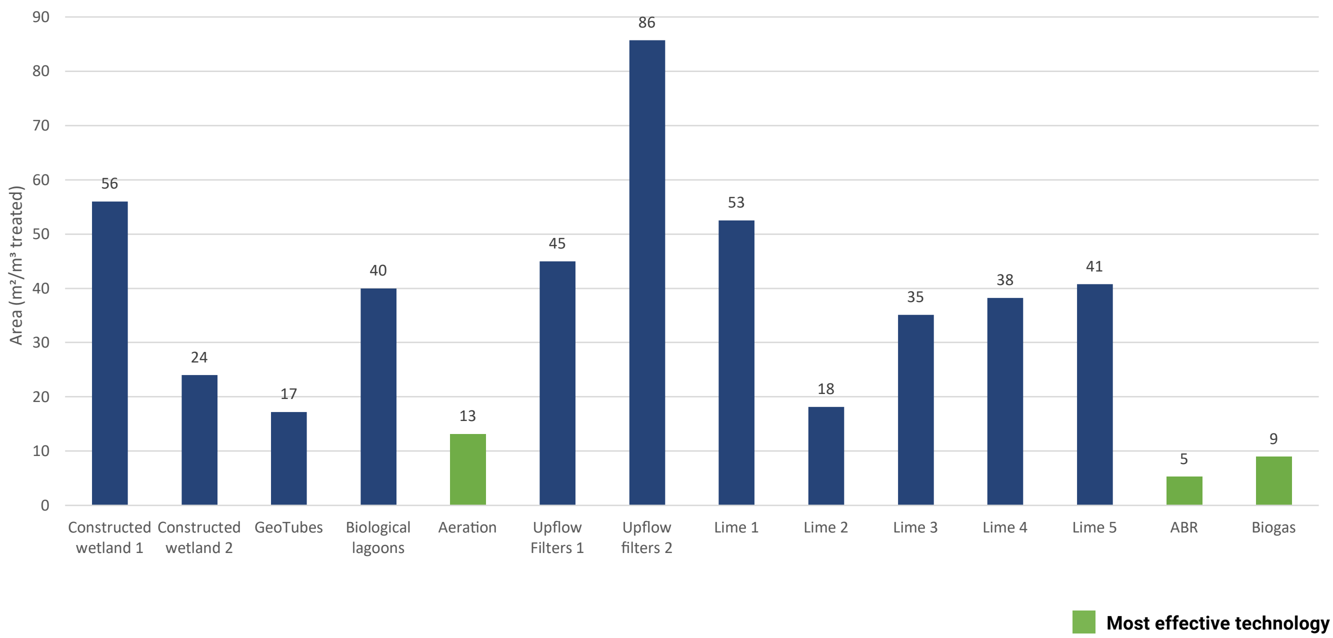
The comparison of the technologies against the key indicators is given in Table 1 below. A scoring system of one (most effective shown in green) to five (least effective shown in red) has been applied for each indicator with the scoring rationale noted. A score against the full list of indicators is given in Appendix B1 with full information/explanation presented against each in Appendix B2.

The scores of each technology have been totalled to give an indication of the most effective choice overall. This has shown that upflow filters (with pre-settlement) are the best for decentralised FSM and the anaerobic lagoons best for centralised FSM. Although these technologies have the lowest/best scores, they still have limitations and selection should be informed by site conditions, i.e. they are not always the most appropriate technology for given site conditions. Section 5 provides guidance on selecting the most appropriate FSM technology for the context.

Comparison of footprint area and costs were two indicators of particular interest in this study. A comparison of these indicators is given in Figure 1 to Figure 3. These have been normalised by m^3 treated and presented in US dollars ($).[10]

The footprint area comparison (Figure 1) shows that the ABR, aeration and biogas systems have the lowest footprint area per m^3 treated. However, these three sites do not include space for solids handling and disposal (see section 6). The technologies that provide full FS treatment and have the lowest footprint area are the lime treatment[11] sites.

Figure 1
Area required by each technology (m^2/m^3 treated)



The costs comparison includes CAPEX ($ per m³ treated), OPEX ($ per m³ treated) and the WLC ($). The WLC assumes the plant operates for 10 years and includes the initial CAPEX, OPEX for 10 years and CAPEX repeats, i.e. the capital costs of items that need to be replaced within 10 years. This showed that the upflow filters, ABR and biogas plants have the lowest WLC. This is due to the low OPEX of these systems and longevity of materials used, so a low number of CAPEX repeats. Lime had a relatively high WLC due to the high OPEX (cost of hydrated lime). See the cost comparison in Figure 2 and Figure 3.

The centralised systems (biological and aeration) had a relatively high CAPEX due to the size of the infrastructure, so a higher WLC. In particular the anaerobic lagoons have a low OPEX and low CAPEX repeats, but because the initial CAPEX is relatively high so is the WLC.

In an emergency context it is hard to determine the required design life for the FSM plant, i.e. the length of time the plant will be required for. Several of the smaller, decentralised sites in CXB use locally available materials such as bamboo.

Although this is good for rapid deployment and is readily replicable, it adds to the WLC as these materials have a shorter life and may need to be replaced several times within a 10-year period, e.g. bamboo last two to three years. This has been considered in the CAPEX repeats.

(10) Exchange rate calculated from Bangladesh Taka February 2019
(11) See section 6.6 for description of 'Lime 1' to 'Lime 5'

Figure 2
Whole Life Cost for 10 years

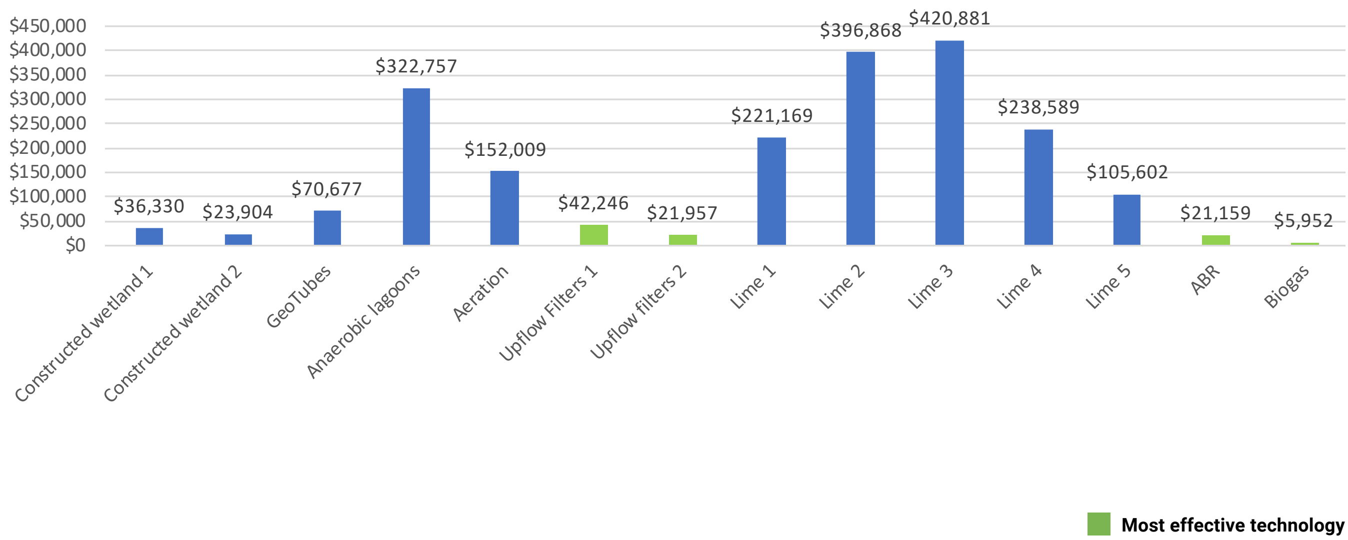
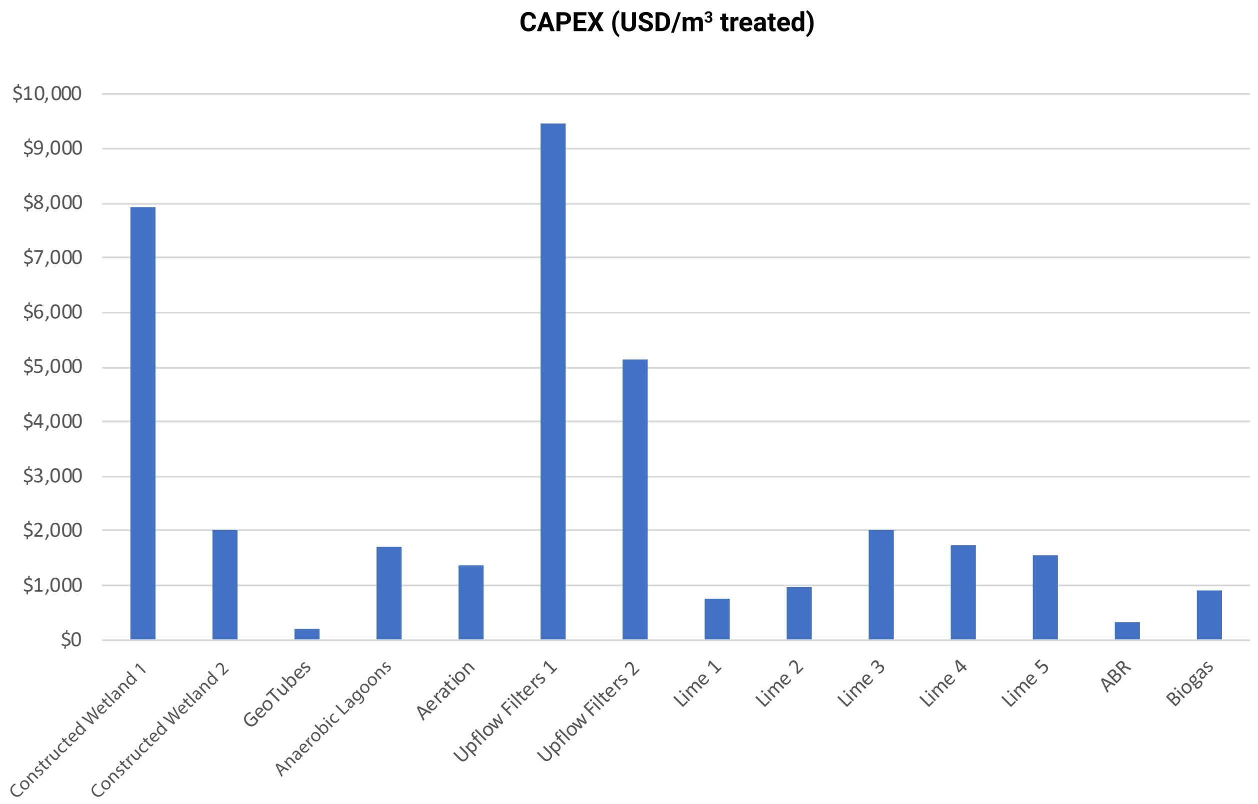
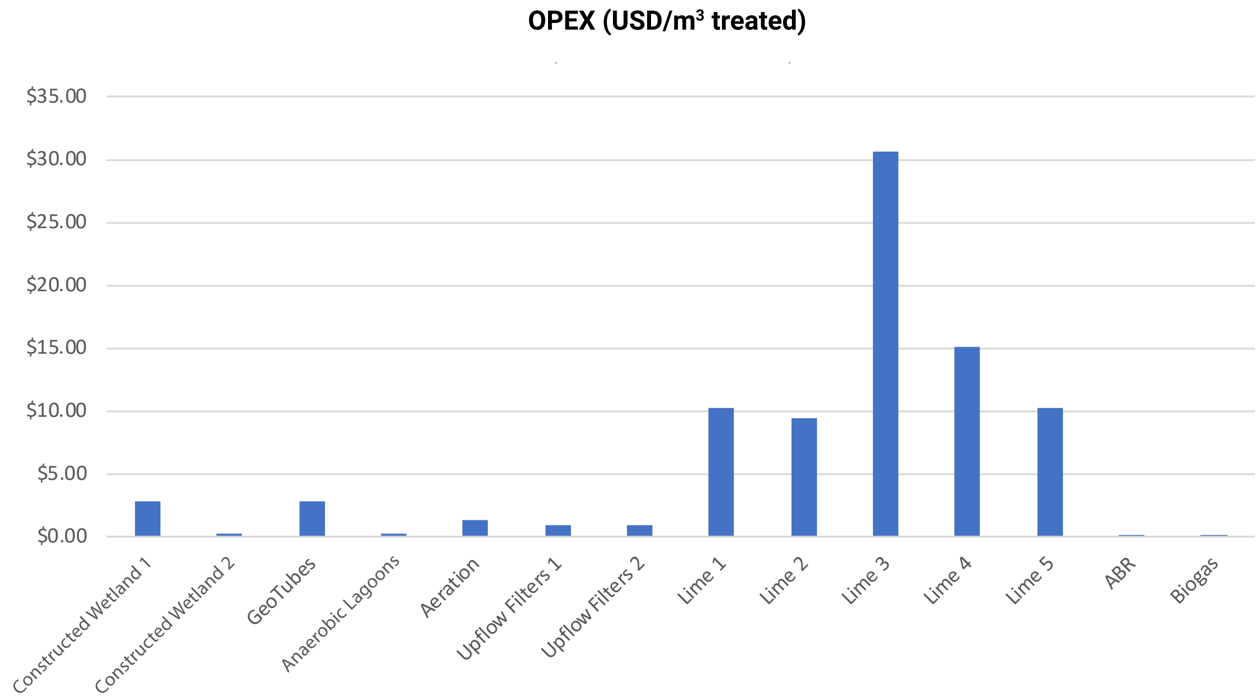


Figure 3
CAPEX and OPEX comparison





General view of CXB camp

Table 1:
Comparison matrix of key indicators

		Decentralised biological and/or mechanical treatment				Decentralised biological treatment				Decentralised chemical treatment			
		Upflow filters	Upflow filters with pre-settlement (metal/ tarp tanks)	Upflow filter with pre-settlement (plastic tanks)	GeoTubes	Constructed wetlands 1	Constructed wetlands 2	Biogas plants	Septic/retention-tanks/ABR	Lime 1 Lagoon lime treatment with dewatering bed	Lime 2 Lagoon lime treatment with dewatering bed	Lime 3 Lagoon lime treatment with dewatering bed	Lime 4 In-barrel treatment with dewatering beds
Technology	*Scale*	1	1	1	1	3	3	4	4	2	2	3	2
	Complexity of technology and equipment	2	2	2	1	2	2	3	2	3	2	3	3
	Layout and footprint area	3	3	5	2	4	3	1	1	4	2	3	3
	Speed of construction and setup	2	2	1	2	3	3	3	2	1	1	3	1
	Resilience to disaster	1	1	2	4	4	4	4	4	2	2	3	2
(Treatment) Process	*Complexity of process (primary, secondary, tertiary)*	2	2	2	2	3	3	3	3	3	3	3	3
	Robustness/ stability	3	3	3	2	3	3	3	3	2	2	2	2
	Treatment effectiveness	3	3	2	4	3	3	4	4	2	2	2	2
Operation and maintenance	*Skills requirements*	2	2	2	2	2	2	3	2	4	4	4	4
Cost	*CAPEX ($/m^3 treated)*	5	5	4	1	5	3	2	1	2	2	3	3
	OPEX ($/m^3 treated)	2	2	2	2	2	1	1	1	4	3	5	4
	WLC	2	2	2	3	2	2	1	2	5	5	5	4
Environmental and social context	*Final discharge routes (environmental contamination)*	2	2	1	5	3	4	4	4	2	4	3	2

Lime 5 3-tank lime system	Centralised biological treatment Anaerobic lagoons	 Aerobic treatment	SCORING RATIONAL (For full scoring rationale refer to Appendix B1)		
4	5	2	*1 is works at multiple scales. Quick and easy to scale up*	1 ● ● ● 5	*5 is only works (well) at one scale. Difficult to scale up/down*
2	2	5	*1 is up to three main items of equipment (e.g. tank, basin, pump, filter) used, which are simple to maintain and operate*	1 ● ● ● 5	*5 is five or more technology units used, which are complex to maintain and operate*
3	3	1	*1 is 0-15m²/m³ treated*	1 ● ● ● 5	*5 is more than 60 m²/m³ treated*
1	4	2	*1 is less than one month*	1 ● ● ● 5	*5 is more than four months*
2	2	3	*1 is resilient to flooding and earthquake (integral to the technology/layout)*	1 ● ● ● 5	*5 is low/no resistance to flooding or earthquake*
3	2	4	*1 is up to 3 simple processes using the same removal mechanism, simple to commission and keep working*	1 ● ● ● 5	*5 is more than 5 complex process with a mix of removal mechanisms, complicated to commission and keep working*
2	3	4	*1 is whole process is not sensitive to changes in influent, inputs (chemicals, aeration etc.) or changes in environmental conditions*	1 ● ● ● 5	*5 is a majority of the process is highly sensitive to changes in influent, inputs (chemicals, aeration etc.) or environmental conditions which will reduce the final effluent quality*
2	2	2	*1 is final liquid and solids meets all DoE standards, WHO standards and is classified as 'good' under CXB FSM strategy*	1 ● ● ● 5	*5 is site classed as 'unacceptable' under CXB FSM strategy and does not meet DoE or WHO coliform standards for liquid effluent*
3	3	5	*1 is low skills needed i.e. no skilled labour required*	1 ● ● ● 5	*5 is highly skilled labour needed throughout operation*
3	3	3	*1 is $0 to $500*	1 ● ● ● 5	*5 is $5000 +*
4	1	2	*1 is up to $0.5/m³ treated*	1 ● ● ● 5	*5 is more than $15/m³ treated*
4	5	4	*1 is less than $20,000*	1 ● ● ● 5	*5 is $200,000 +*
2	1	2	*1 is 'good' discharge routes, i.e. in line with CXB FSM strategy, e.g. infiltration, burial, incineration. Clearly planned disposal route and adequate space given*	1 ● ● ● 5	*5 is poor allowance for and difficult management of final products/waste*

5 TECHNOLOGY SELECTION

The following section outlines the most appropriate choice of technology in various site conditions. The intention is to inform decision making for FSM technology selection in a variety of future contexts. Site-specific factors and routes for the final disposal of liquids and solids have the greatest influence on technology selection and plant design. These factors should be considered along with the recommendations below.

Table 2: Technology selection based on indicators

INDICATOR	BEST FOR	BEST TECHNOLOGY	RATIONAL
Technology	*Easy scale up*	**Upflow Filters**	Can be used on multiple scales. Easy to add more (prefabricated tanks) units in parallel
	Low complexity	**GeoTubes**	Simple technology using local materials
	Footprint area/space i.e. lowest footprint area per m^3 treated	**Aeration (centralised) or ABR (for decentralised)**	Lowest footprint area per m^3 treated
	Speed of construction and setup	**Upflow Filters**	Prefabricated tanks at ground level so construction is rapid
	Resilience to disaster	**Upflow Filters**	Prefabricated tanks (not concrete) so earthquake resistant. All main process units are above ground level so good for flooding
(Treatment) Process	*Complexity (primary, secondary, tertiary)*	**Upflow Filters and GeoTubes**	Simple process
	Robustness/stability of process	**Lime**	Lime dose can be adjusted to suit influent. Lime treatment provides full treatment to achieve pathogen kill
	Treatment effectiveness	**Aeration or lagoons**	Best for public health and environmental effluent standards
O&M	*Skills requirements*	**ABR**	Solids removal every 6 to 12 months otherwise limited maintenance needed
Cost	*Capital expenditure costs (CAPEX $/m³ treated)*	**ABR**	Lowest CAPEX per m^3 treated
	Operational expenditure (OPEX $/year)	**Upflow Filters or Constructed Wetland**	Lowest OPEX per m^3 treated
	The whole life costs (WLC) of each technology	**Constructed Wetland ABR or Biogas**	Lowest WLC. ABR is a concrete structure so should not need any replacement over 10 years
Environmental and social context	*Insights on understanding final discharge routes (environmental contamination)*	**Upflow Filters**	Had adequate space for infiltration and solids storage to achieve pathogen inactivation. Process is contained (in closed plastic tanks) so limits vectors

A multi-criteria analysis tool has been created by Arup, which allows designers to weight each indicator according to importance, ordering them from 1 to 10. For example, if the footprint area is the most important factor in their planning/design, they would weight that factor as ‘most important’. This weighting is then applied to the ranking of each technology and the tool will show the designer the technologies ranked best to worst according to their weighting. The tool is presented in Appendix F.

RISK WITH CHOICE
- Effluent quality To Be Confirmed[12] (TBC) - Area needed for liquid infiltration and solids burial, or additional treatment (to achieve standards)
- Effluent quality does not meet public health standards. Needs additional treatment (to achieve standards)
- Effluent quality TBC - Area needed for liquid infiltration and solids burial, or additional treatment (to achieve standards) - Aeration needs skilled operator and power supply
- Effluent quality TBC - Area needed for liquid infiltration and solids burial, or additional treatment (to achieve standards) - Site specific conditions must be considered with this criteria, resilience to disaster'. e.g. If site is in a known flood plain, the designer could consider raising technology above flood level or providing flood protection bunds/walls. In this case a technology with larger civil works maybe more appropriate e.g. lagoons or concrete tank system.
- Effluent quality TBC - Area needed for liquid infiltration and solids burial, or additional treatment (to achieve standards)
- High OPEX
- High skills needed to operate
- Effluent quality TBC - Area needed for liquid infiltration and solids burial, or additional treatment (to achieve standards) - Concrete tanks so permanent structure - Scale up difficult
- Area needed for solids handling and disposal
- Effluent quality - Area needed for liquid infiltration and solids burial
- Effluent quality - Area needed for liquid infiltration and solids burial - Scale up difficult for concrete ABR
- Effluent quality - Area needed for liquid infiltration and solids burial, or additional treatment (to achieve standards)

(12) Effluent has not (yet) been tested in CXB so there is no evidence to support treatment effectiveness and pathogen removal.

6 TECHNOLOGY REVIEW

This technology review presents the findings from the site data. The advantages and disadvantages of each technology against the key indicators are given along with a process flow diagram (PFD) and site layout plan. The full assessment for each site is given in Appendix B2.

Upflow Filters

DESCRIPTION

Two NGOs were using upflow filters, each with different features and treatment mechanisms. Four sites were visited by Arup, two for each NGO. Two main types of upflow filter were visited, i.e. with and without pre-settlement.

The upflow filters are tanks where the inlet is below the outlet level forcing upflow and anaerobic conditions. Several filters are arranged in series with progressive solids removal and liquids overflow. Solids are removed from the bottom zone of the tanks and disposed of. Liquids pass forward from the top of the tanks for further treatment or disposal. The treatment mechanism is solids/liquid separation by settlement and filtration as well as some digestion of solids under anaerobic conditions.

The first NGO visited (NGO 1) was using 'assemble on site' type tanks (steel structures lined with tarpaulin) see Images 1 to 4. They had originally used three upflow filters in series followed by a constructed wetland and soak pit for liquid disposal and three burial pit for solids storage. This system had been upgraded in December/January 2019 (due to solids blocking the first and second filters), with the first two filters converted to settlement tanks and followed by an upflow filter, with a constructed wetland and soak pit for liquid disposal. There was one solids burial pit per upflow filter, with a (valve controlled) solids discharge located at the base of each settlement tank and the filter. The final disposal of solids was planned to be to a vermiculture or solid waste plant operated by the same NGO in Camp 5 and Camp 17. This additional solids treatment/disposal incurs additional costs and requires a larger footprint area. The filter media used was select sand, stone and carbon. PFDs and site layouts of the plants, with and without presettlement, are shown in Figure 4 to Figure 11.

The second site visited (NGO 2) were using 10,000 litre plastic tanks for settlement and reactor tanks with fixed filter media (coconut husks). They had two upflow settlement tanks followed by two upflow filters. Anaerobic conditions are maintained in the closed plastic tanks so they operate as fixed media reactors (or biofilm reactors). Solids were discharged (valve controlled) from the bottom of each tank into soak pits, two per filter, with capacity for two years of solids storage, i.e. allowing time for adequate pathogen die-off. Liquids were disposed of in an infiltration trench, and there is a buffer tank and (optional) chlorination upstream of the infiltration trench. The additional features used by NGO 2 should achieve a better pathogen kill, i.e. (optional) disinfection of liquid effluent and two years storage capacity for solids. A PFD and site layout are shown in Figure 10 and Figure 11.

DECENTRALISED BIOLOGICAL AND/OR MECHANICAL TREATMENT: **UPFLOW FILTERS**

PROCESS FLOW DIAGRAM AND SITE LAYOUT - PLANT 1

Figure 4:
PFD - Upflow filter plant 1 (NGO 1)

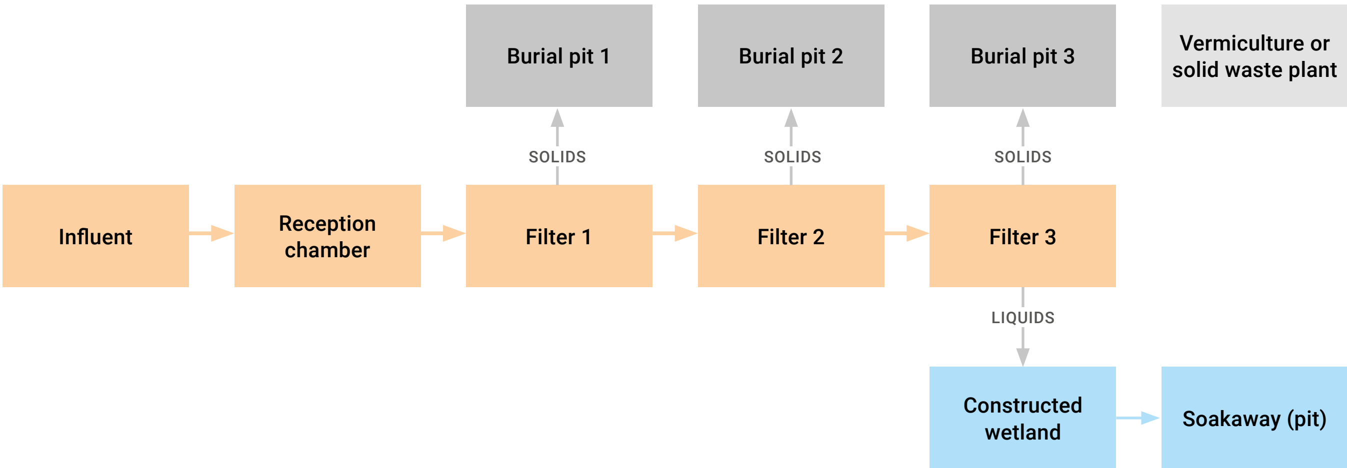
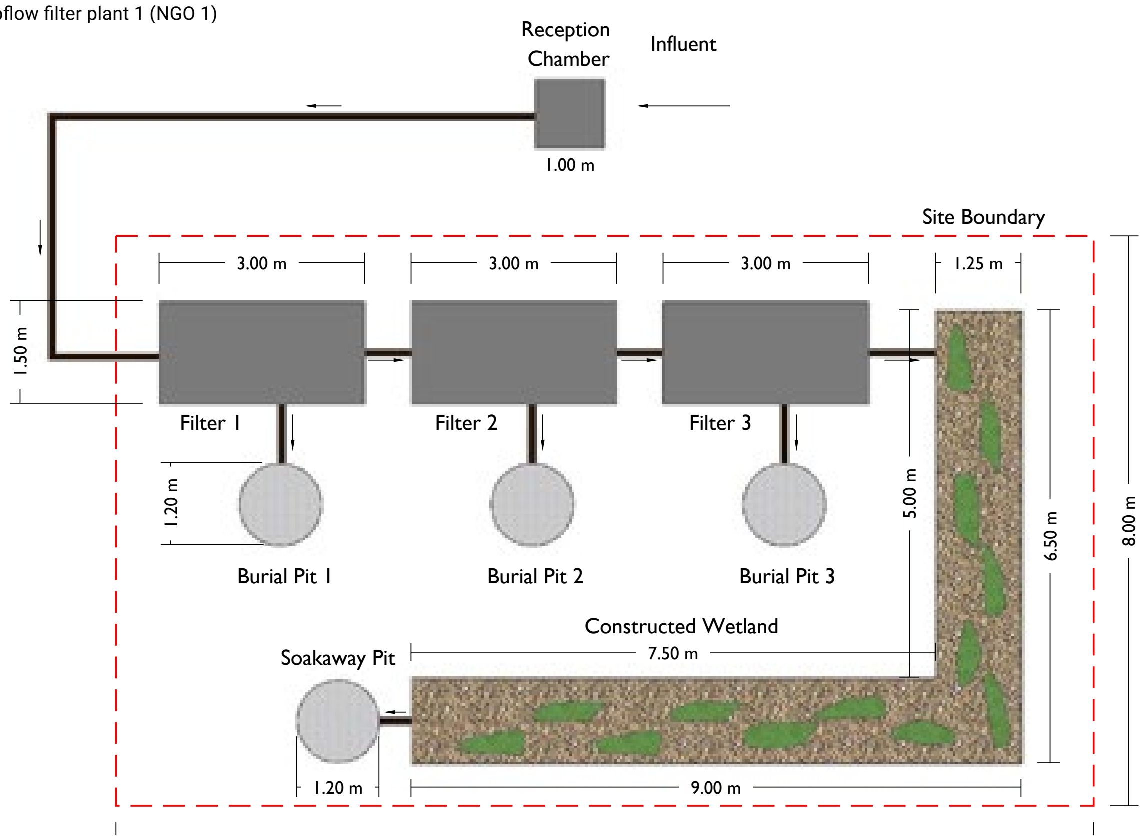
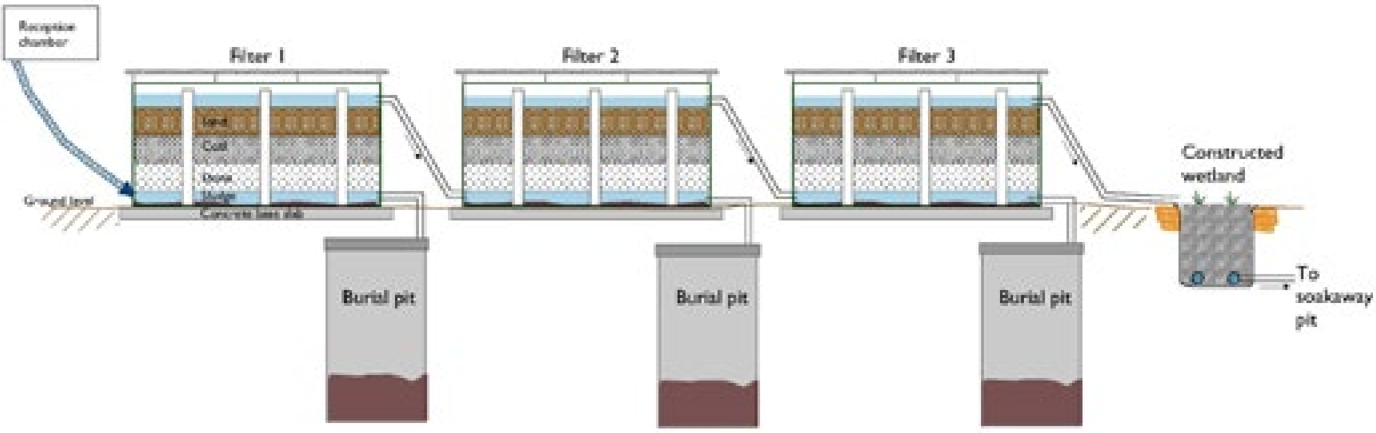


Figure 5:
Site layout plan - Upflow filter plant 1 (NGO 1)



DECENTRALISED BIOLOGICAL AND/OR MECHANICAL TREATMENT: **UPFLOW FILTERS**

Figure 6:
Upflow filter plant 1 (NGO 1) cross sections



PHOTOS - PLANT 1

Image 1:
Plant 1 (NGO 1) - Upflow Filters

Image 2:
Plant 1 (NGO 1) - Constructed Wetland liquid treatment

DECENTRALISED BIOLOGICAL AND/OR MECHANICAL TREATMENT: **UPFLOW FILTERS**

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA - PLANT 1

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		2m³ per day
	Scale/scalability	1	- More settlement tanks and filters could be added in sets of three in parallel
	Footprint area and access	3	- The area for treatment units is 91m² - The site is a total of approximately 110m² - The layout is efficient because it uses rectangular tanks and an L-shaped constructed wetland
	Speed of construction and setup	2	- Civil construction takes approximately 1 month (40 labourers and 4 engineers). There is also off-site work on filter units (e.g. metal and welding) required. - Metal work comes flat packed and is bolted together on site. - It takes approximately 20 days to get the process operating correctly once constructed
	Resilience to disaster	2	- Soil built up to protect the sites from flooding - All tanks above ground level
TREATMENT PROCESS	**Complexity of treatment process**	2	- Simple, runs by gravity with limited operator intervention - Solids need desludging from each filter once per month - Solids need emptying every 6 to 12 months. Access to empty soak pits is difficult
	Treatment effectiveness	3	- Initial findings (from UPM) show the systems meet the DoE liquid effluent standards with the exception of Biological Oxygen Demand (BOD), total nitrogen and coliform level. - Data also showed the helminth and coliform levels in the solids pits were still too high for public health standards (WHO reuse standards)
	Pinch point	3	- Liquid soak pit i.e. infiltration capacity - Solids storage capacity
	Final discharge routes	2	- After 10 months of operation, solids burial pits were emptied and disposed of via vermiculture, solid waste plants or biogas plants operated by the same NGO - Liquid is infiltrated in the soak pit.
OPERATION AND MAINTENANCE	**O&M skills requirements**	2	- Daily site checks by skilled labour (18 FSM sites in total) - Solids need to be discharged to burial pits once per month - After 1 year of operation, staff found filters blocked, so had to remove and replace media and discovered that the 1st and 2nd burial pits were full, hence the upgrade to settlement tanks
COSTS	**CAPEX**	5	- $21,420 - $10,710 per m³ treated
	OPEX	2	- $634 per year - Labour costs only - $0.87 per m³ treated
	WLC	2	- $47,000, assuming a plant life of 10 years and that 90% of materials need to be totally replaced once in that period

Most effective ◀ 1 ● ● ● 5 ▶ Least effective

Table 3:
Advantages and disadvantages of upflow filters (Plant 1)

DECENTRALISED BIOLOGICAL AND/OR MECHANICAL TREATMENT: **UPFLOW FILTERS**

PROCESS FLOW DIAGRAM AND SKETCH - PLANT 2

Figure 7:
PFD - Upflow Filter plant 2 (NGO 1)

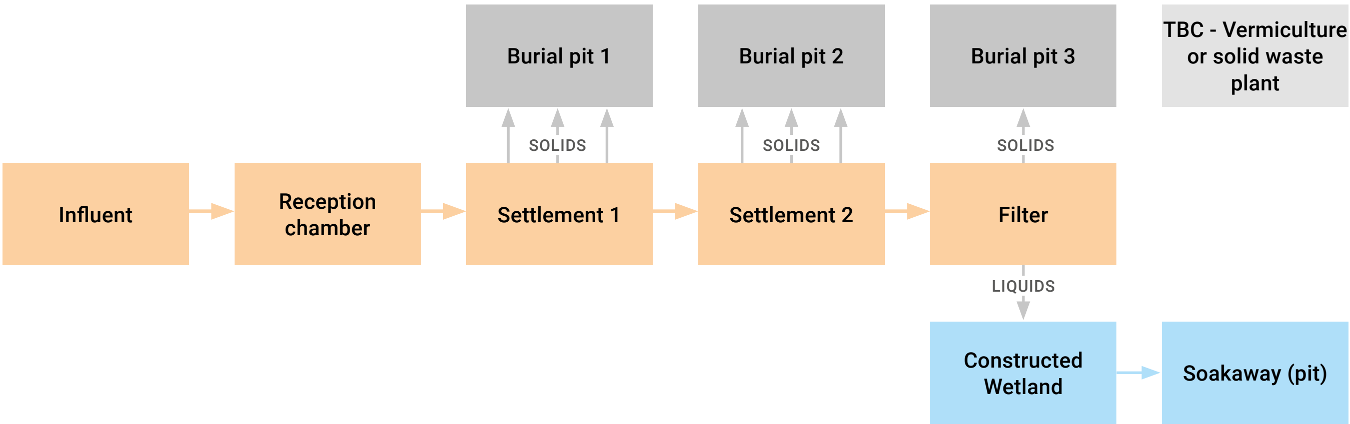
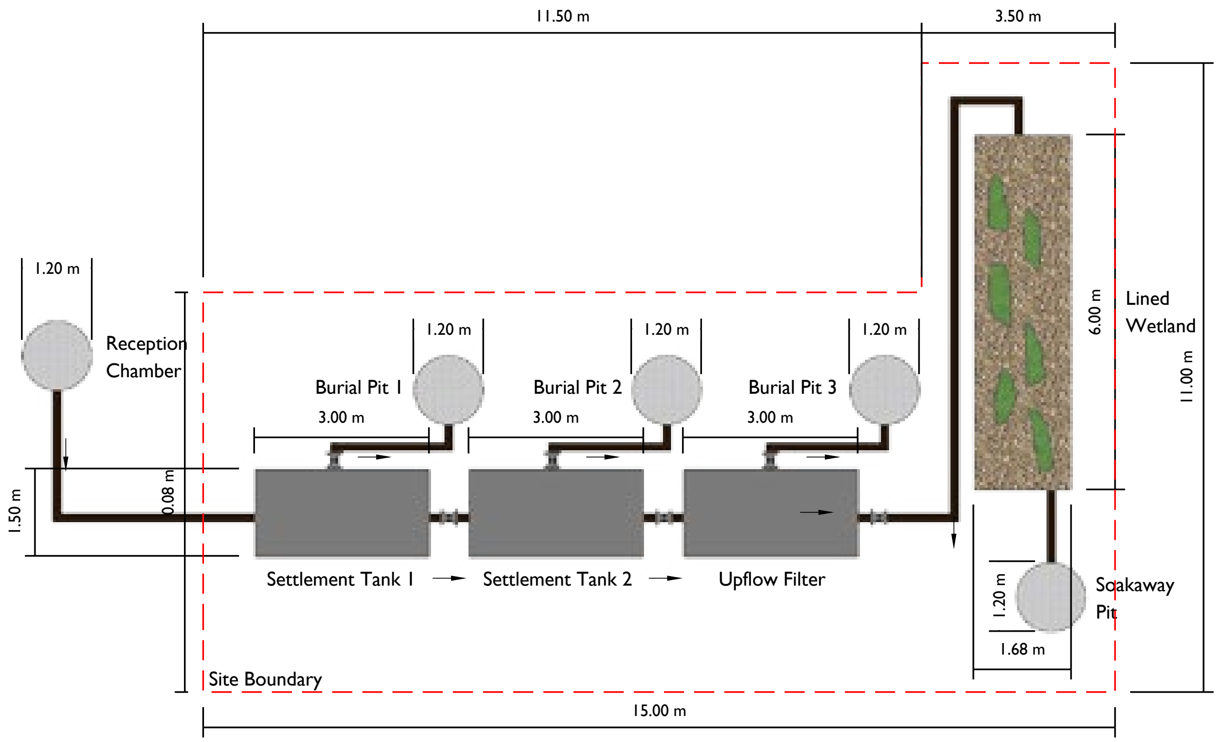
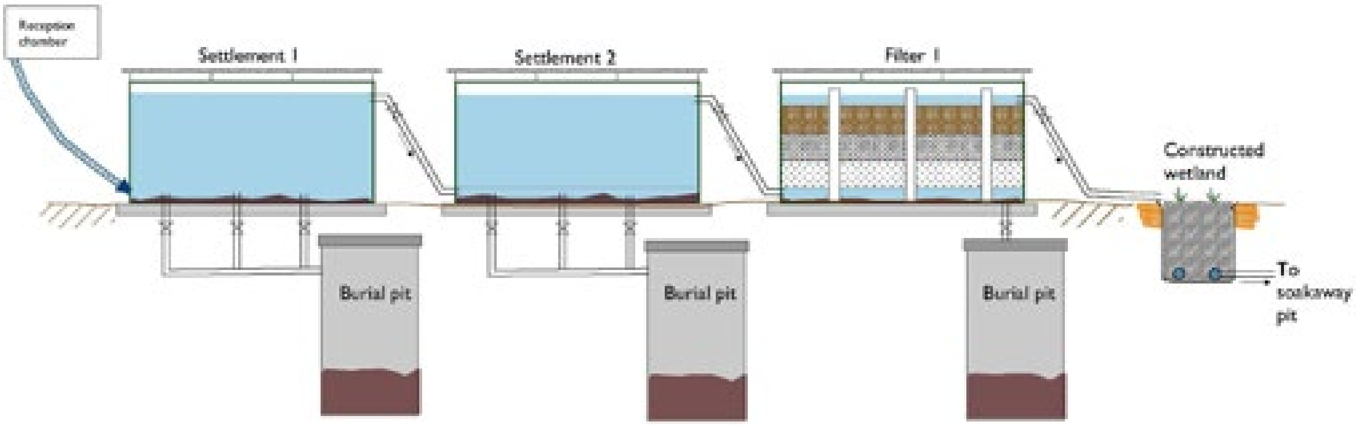


Figure 8:
Site layout plan - Upflow Filter plant 2 (NGO 1)



DECENTRALISED BIOLOGICAL AND/OR MECHANICAL TREATMENT: **UPFLOW FILTERS**

Figure 9:
Upflow Filter plant 2 (NGO 1) cross sections



PHOTOS - PLANT 2

Image 3:
Plant 2 (NGO 1) - Pipework between filters

Image 4:
Plant 2 (NGO 1) - Solids removal pipework

DECENTRALISED BIOLOGICAL AND/OR MECHANICAL TREATMENT: **UPFLOW FILTERS**

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA - PLANT 2

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		2m3 per day
	Scale/scalability	1	- More filters could be added in sets of 3 in parallel
	Footprint area and access	3	- The area for treatment units is 91m^2 - The site is a total of approximately 110m^2 - The layout is efficient because the filters and wet tank are rectangular
	Speed of construction and setup	2	- Civil construction takes approximately 1 month (40 labourers and 4 engineers). Off-site work on filter units (e.g. metal work and welding) is also required - Metal work comes flat packed and is bolted together on site - Approximately 20 days is needed to get the process operating correctly once constructed
	Resilience to disaster	2	- Soil built up to protect the sites from flooding - All tanks above ground level
TREATMENT PROCESS	**Complexity of treatment process**	2	- Simple, runs by gravity with limited operator intervention - Solids needed desludging from each filter once per month - Solids needed emptying every 6 to 12 months. Access to empty soak pits is difficult
	Treatment effectiveness	3	- Initial findings (from UPM) show the system meets the DoE liquid effluent standards with the exception of BOD, total nitrogen and coliform levels - Data also showed the helminth and coliform levels in the solids pits were still too high for public health standards (WHO reuse standard)
	Pinch point	3	- Liquid soak pit, i.e. infiltration capacity - Solids storage capacity
	Final discharge routes	2	- After 10 months of operation, solids burial pits were emptied and disposed of via vermiculture or biogas plants operated by the same NGO - Liquid is infiltrated in the soak pit
OPERATION AND MAINTENANCE	**O&M skills requirements**	2	- Daily site checks by skilled labour (18 FSM sites in total) - Solids need to be discharged to burial pits once per month - After 1 year of operation staff found filters blocked, so had to remove and replace media, and discovered that the 1st and 2nd burial pits were full, hence the upgrade to settlement tanks
COSTS	**CAPEX**	5	- $21,420 - $10,710 per m^3 treated
	OPEX	2	- $634 per year - Labour costs only - $0.87 per m^3 treated
	WLC	2	- $47,000, assuming a plant life of 10 years and that 90% of materials need to be totally replaced once in that period

Most effective ◀ 1 ● ● ● 5 ▶ Least effective

Table 4:
Advantages and disadvantages of upflow filters (Plant 2)

DECENTRALISED BIOLOGICAL AND/OR MECHANICAL TREATMENT: **UPFLOW FILTERS**

PROCESS FLOW DIAGRAM AND SKETCH - PLANT 3

Figure 10:
PFD - Upflow Filter plant 3 (NGO 2)

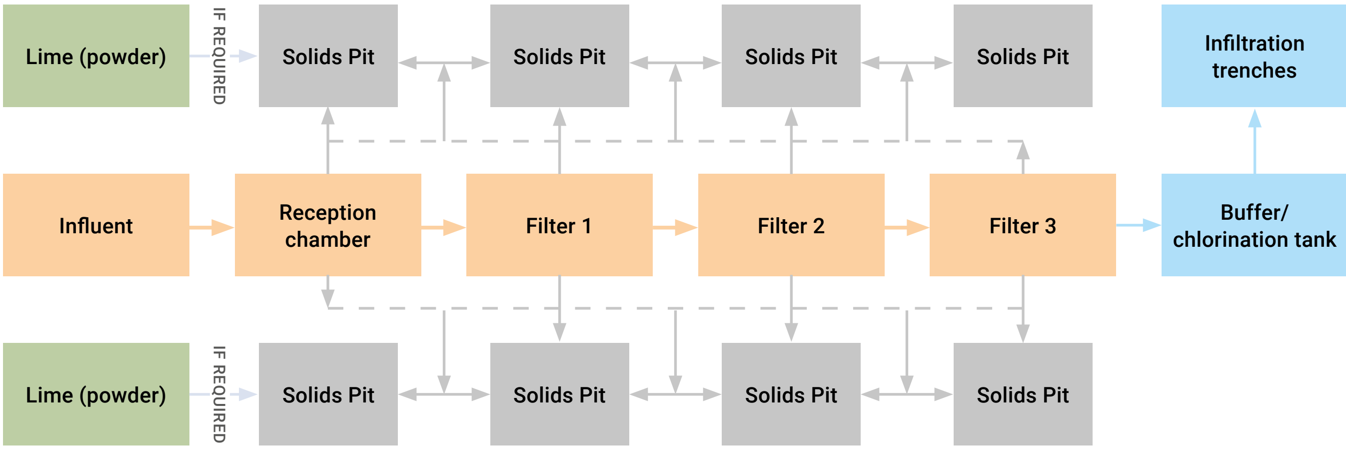
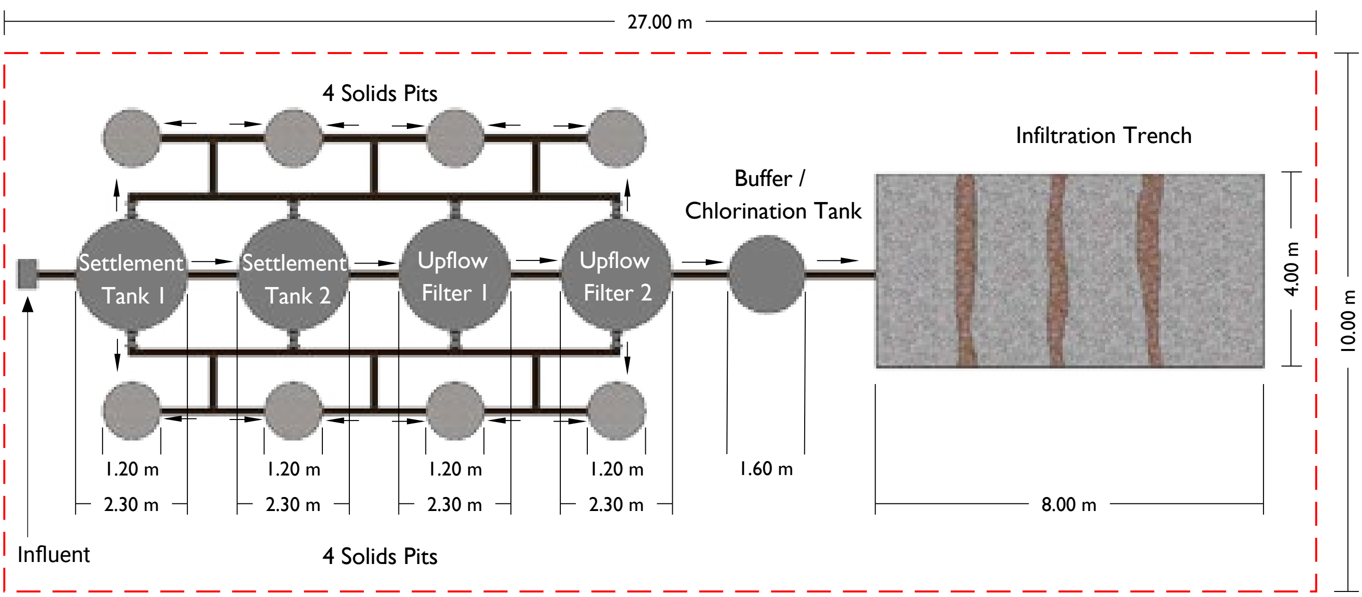


Figure 11:
Site layout plan - Upflow Filter plant 3 (NGO 2)



DECENTRALISED BIOLOGICAL AND/OR MECHANICAL TREATMENT: **UPFLOW FILTERS**

PHOTOS - PLANT 3

Image 5:
NGO 2 - Upflow filters (under construction)

Image 6:
NGO 2 - Upflow filters solids storage

Image 7:
NGO 2 - Upflow filters infiltration trenches

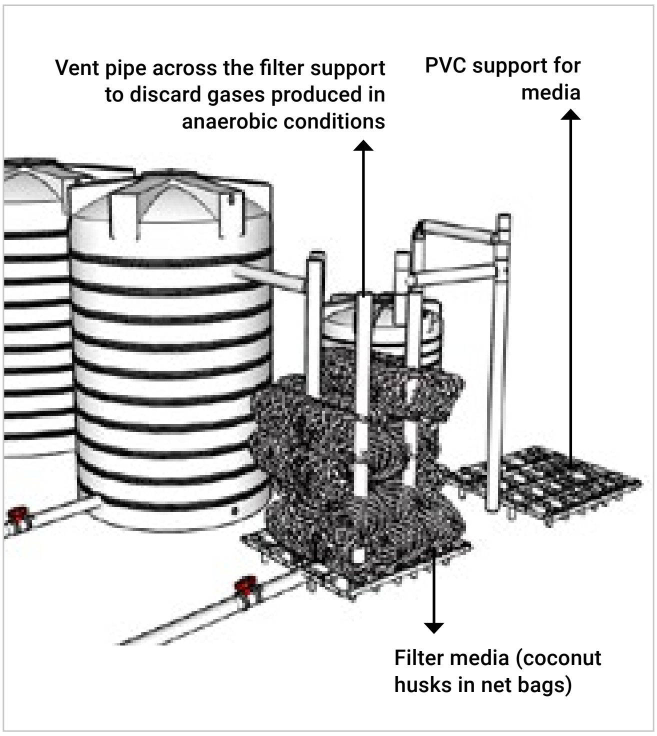


Image 8:
NGO 2 - Sketch showing internal structure of upflow filter plant 3

DECENTRALISED BIOLOGICAL AND/OR MECHANICAL TREATMENT: **UPFLOW FILTERS**

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA - PLANT 3

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		1.75m³ per day
	Scale/scalability	1	- More settlement tanks and filters could be added in parallel
	Footprint area and access	5	- The area for treatment units is 150m² - Layout is flexible due to prefabricated tanks, i.e. tanks can be arranged to suit site shape
	Speed of construction and setup	1	- 2 weeks if all the materials area available - Using prefabricated plastic tanks helps ensure quick construction
	Resilience to disaster	2	- Prefabricated plastic tanks are not fixed to a base so maybe unstable in floods or earthquakes - Design modifications could be made to improve resilience
TREATMENT PROCESS	**Complexity of treatment process**	2	- Simple system that runs by gravity with limited operator intervention - Solids need desludging from each filter once per month - Solids need emptying every 2 years. Access to empty soak pits is difficult
	Treatment effectiveness	2	- No test data available - Pathogen kill achieved through disinfection of liquid waste and storage time for solids, i.e. 24 months - There are 2 solids pits per tank to allow 1 to rest whilst the other is in use
	Pinch point	3	- Liquid infiltration, i.e. infiltration capacity of the soil and space for infiltration trench - Infiltration rate of 8.3 l/hr/m² used (semi-saturated soil). Should be adopted following field testing
	Final discharge routes	1	- Liquid goes to the infiltration trench, which appeared to be adequately sized - Solids go to a storage pit and can be used as soil improver/compost after sufficient time - Solids pits can be shallower and wider if the groundwater level is high
OPERATION AND MAINTENANCE	**O&M skills requirements**	2	- Plant runs using gravity - One skilled labourer required to carry out regular checks twice per week - Solids emptying done via valves - May be difficult to tell when desludging is required. Limited access/visibly to see solids carry-over problems - Chlorination tank available at end if disinfection is required, e.g. if there is a cholera outbreak
COSTS	**CAPEX**	4	- $9,000 - $5,150 per m³ treated
	OPEX	2	- $575 per year - Labour costs only - $0.90 per m³ treated
	WLC	2	- $21,957, assuming a plant life of 10 years, and that 80% of materials need to be totally replaced once in that period

Most effective 1 ● ● ● 5 Least effective

Table 5:
Advantages and disadvantages of upflow filters (Plant 3)

6.2 DECENTRALISED BIOLOGICAL AND/OR MECHANICAL TREATMENT: **GEOTUBES**

GeoTubes

DESCRIPTION

GeoTubes were a novel FSM technology being used by one NGO in three camps in CXB. Arup visited a site in Camp 15. The FSM PFD and layout are shown in Figure 12 and Figure 14.

A GeoTubes is a geotextile tube located on a bamboo platform above a primary filter. Incoming sludge (carried in barrels from desludged latrines), is discharged through a mesh screen and gravitates (via a flexihose) into the GeoTubes. Solids are retained within the tube, and liquids drain through the geotextile and either evaporate or gravitate through the primary filter. The primary filter is lined and consists of three layers of filter media (sand, gravel and brick). Liquids then flow (via plastic pipes) to a (brick filled) infiltration bed. Dried solids are periodically emptied from the GeoTubes and buried within the site.

The main treatment mechanism is solid/liquid separation within the GeoTube and the primary filter. The final disposal of solids and liquids (infiltration and burial) limits the human exposure to pathogens.

The site visited included four GeoTubes with one in use and three dewatering/drying. The site that had been allocated to the NGO for FSM, and its size dictated how many GeoTubes they had. Having several GeoTubes at one site gave flexibility in terms of the operation and allowed time for the solids to dry out sufficiently before they were emptied and buried.

The information provided before the site visit (from Octopus) suggested that lime was added to the sludge during collection; however, this was not in use at the site visited by Arup and the NGO stated they were not using lime as part of the treatment process.

The operating NGO had been experimenting with different nylon materials for the GeoTubes as they had found that felt-type geotextiles blocked quickly. There was also a high level of solids carry-over evident from the GeoTubes to the primary filters. The NGO were aware of the issue and working on improvements to overcome it.

The infiltration bed also appeared to be overwhelmed with solids blockages and liquid overflowing to a pond. The NGO were aware of this and were due to complete some infiltration testing to design an appropriately sized infiltration trench.

Due to the problems noted above the NGO were planning to install an Anaerobic Baffled Reactor (ABR) upstream of the GeoTubes to reduce the amounts of solids within the GeoTube influent and also achieve greater overall removal efficiencies in pathogen removal. The GeoTubes would be kept as a secondary treatment process to further treat the liquid effluent from the ABR.

As found by the implementing NGO, GeoTubes do not provided a standalone treatment solution. They provide some solids/liquids separation as part of a wider treatment solution. This should be considered when planning the system.

DECENTRALISED BIOLOGICAL AND/OR MECHANICAL TREATMENT: **GEOTUBES**

PROCESS FLOW DIAGRAM AND SKETCH

Figure 12:
GeoTube PFD

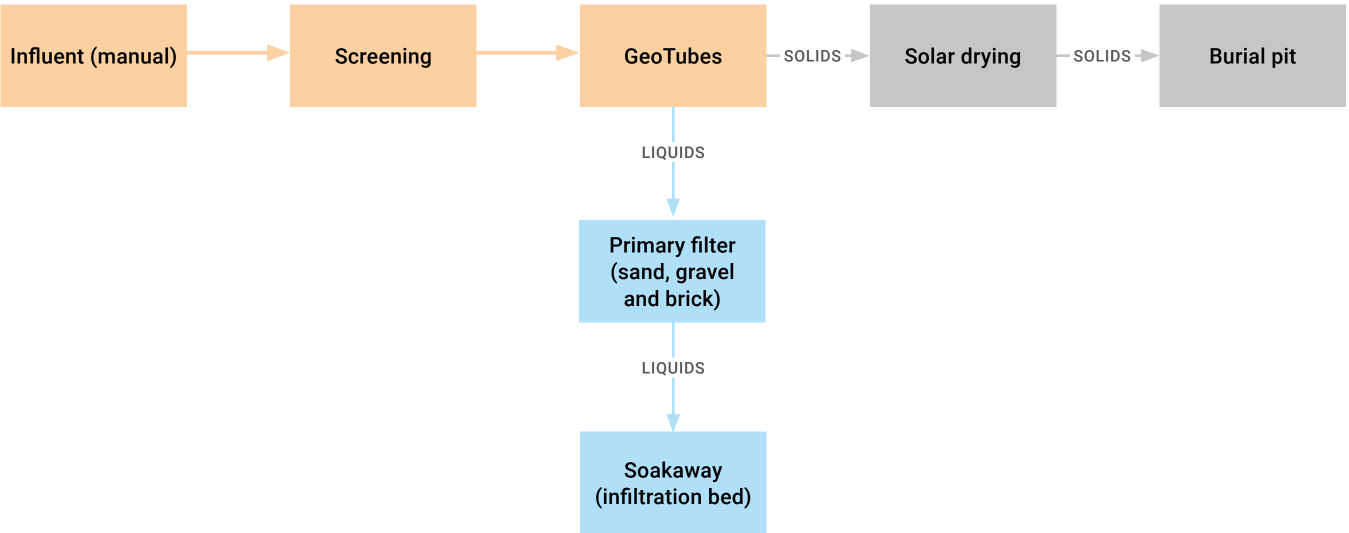
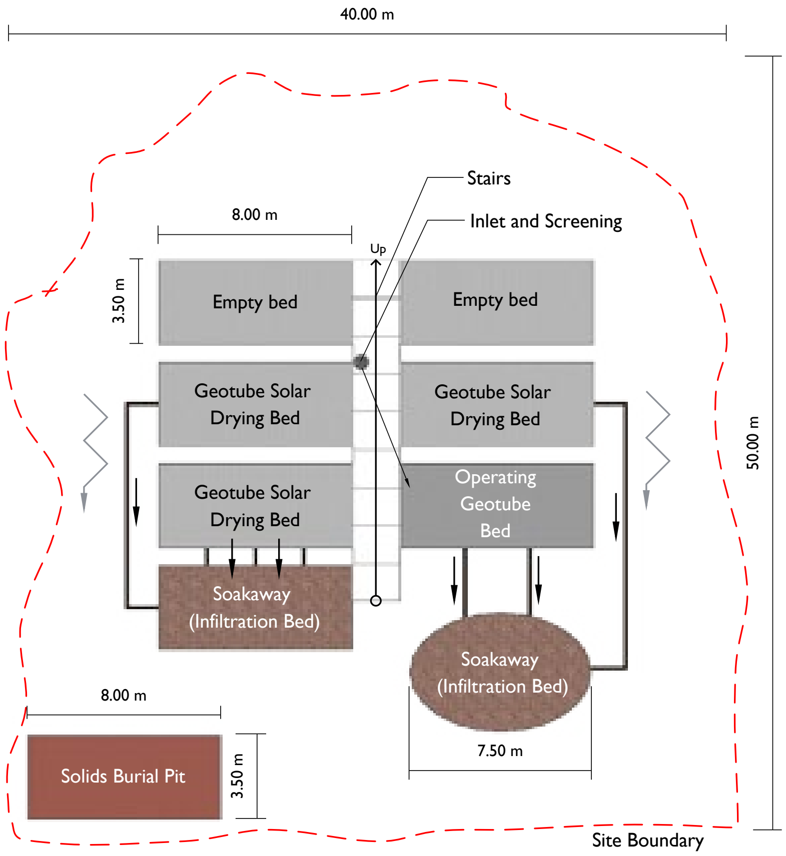
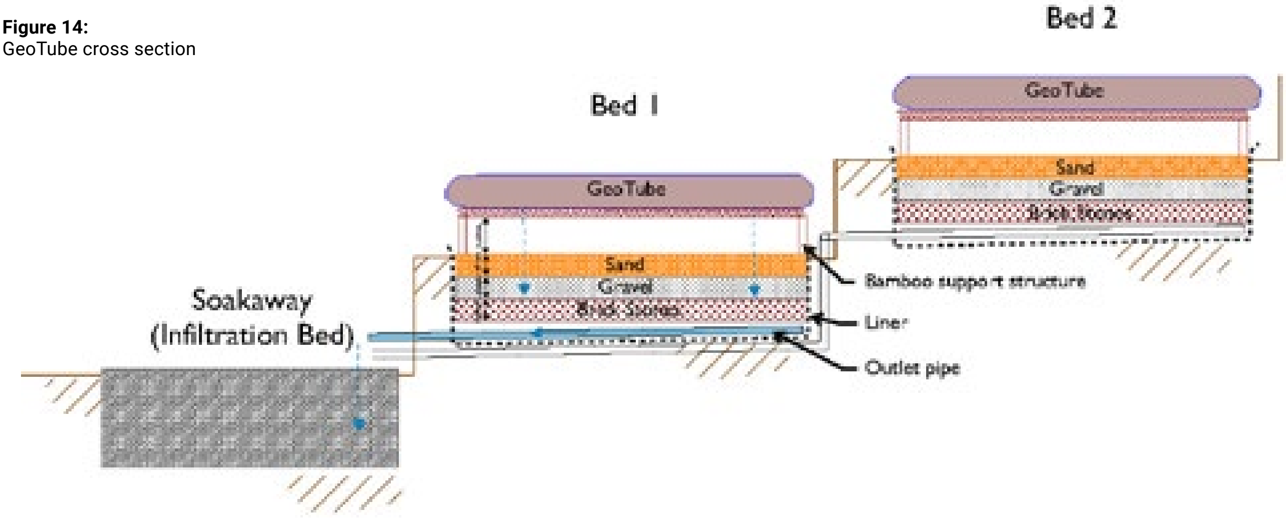


Figure 13:
Site layout plan - GeoTube



DECENTRALISED BIOLOGICAL AND/OR MECHANICAL TREATMENT: **GEOTUBES**

Figure 14:
GeoTube cross section



PHOTOS

Image 9:
GeoTube inlet funnel/screen

Image 10:
GeoTube 'bed' with liquid filter below

Image 11:
GeoTube 'bed'

Image 12:
GeoTube liquid treatment and solids burial pit in background

DECENTRALISED BIOLOGICAL AND/OR MECHANICAL TREATMENT: **GEOTUBES**

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		- The site treated 6 to 7m³ per day - It was estimated to serve a population of 440 - Rotation (GeoTube filling, drying and resting) needs to be carefully managed to optimise capacity/footprint area
	Scale/scalability	1	- Shape and size of each GeoTube and primary filter is flexible and can be designed to suit the site conditions - Each tube was approximately 8×3.5×0.4m (LxDxH), which the NGO stated meant it was a suitable weight for using bamboo structures and easy to empty solids - Process can be scaled up by adding more GeoTubes
	Footprint area and access	2	- Each GeoTube bed is 28m², i.e. 8×3.5m. One is used at a time - The whole site was 2,000m², i.e. 40×50m - Flows are by gravity so it is preferable to have a natural fall on the site or elevate the inlet screen and GeoTube to achieve gravity flows
	Speed of construction and setup	2	- Construction takes 1.5 months with 20 people - The set-up process is simple, i.e. can start straight away following construction - Large amount of ground work (slope cutting and stability) is required
	Resilience to disaster	4	- Simple two-stage process, i.e. solids/liquids separation and liquid filtration
TREATMENT PROCESS	**Complexity of treatment process**	2	- Initial findings from UPM testing show the treatment process is not achieving the required coliform reduction but is achieving helminth standards. However, UPM tested a GeoTube site where lime was mixed with the influent sludge prior to discharge to the GeoTubes (in Camp 21), so results are not representative for the site visited by Arup - For the site visited by Arup (i.e. no lime and poor liquid management with poor infiltration), effluent would be classed as 'unacceptable' under the CXB FSM strategy - With the planned improvements, for example the addition of an ABR upstream and a properly designed liquid infiltration downstream, the site would be 'acceptable' under the CXB FSM strategy
	Treatment effectiveness	4	- Solids are buried within the FSM site (fenced area). This is relatively informal, but the NGO are working to improve the arrangement - Liquids are infiltrated, but the system was overwhelmed and there was ponding on site
	Pinch point	3	- Liquid goes into an infiltration trench which appeared to be adequately sized - Solids go into a storage pit and can then be used as soil improver/compost after enough time - Solids pits can be shallower and wider if the groundwater level is high
	Final discharge routes	5	- Daily site maintenance tasks include setting up influent pipework, clearing the inlet screen, clearing the operating valves, etc. - 3 to 4 site staff required per day (not including staff for desludging)
OPERATION AND MAINTENANCE	**O&M skills requirements**	2	- Daily site maintenance tasks include setting up influent pipework, clearing the inlet screen, clearing the operating valves, etc. - 3 to 4 site staff required per day (not including staff for desludging)
COSTS	**CAPEX**	1	- $1,300 per GeoTube bag including approximate construction costs - $5,200 for a whole site with up to 4 GeoTubes plus solids and liquid filters and disposal - $200 per m³ treated
	OPEX	2	- Approximately $6,700 per year mainly for labour (3 to 4 site staff per day) - Approximately $2.80 per m³ treated
	WLC	3	- $70,677

Most effective ◂ 1 ● ● ● 5 ▸ Least effective

Table 6:
Advantages and disadvantages of GeoTubes

Constructed Wetlands

DESCRIPTION

There are two NGOs in the CXB camps using vertical subsurface flow (VSF) constructed wetlands (CW) for FSM. Three sites were visited by Arup in Camp 6 and Camp 1W. The process flow diagram (PFD) and layout are shown in Figure 15 and Figure 16. One of the two sites visited was poorly managed so results have been excluded from this section but are presented in the comparison in Appendix B.

Vertical subsurface flow constructed wetlands are typically a lined bund or bed that is filled with filter media (e.g. graded gravel or stone) with a top layer of soil and planted with reeds or similar. They have a freeboard allowance for solids accumulation at the top and a sloped bottom to drain liquids.

The main treatment mechanism is solid/liquid separation by filtration through the media bed. The solids accumulate around the plant roots and are stored for sufficient time to achieve biochemical stabilisation and pathogen die-off. Liquids are filtered as they drain through the bed media, separating out remaining solids. A certain amount of biological treatment by micro-organisms also occurs within the constructed wetland. Generally, liquids require further treatment prior to disposal to protect environment and public health.

Each site visited had a single rectangular, lined constructed wetland, with the influent point on the surface at one end. FS flows vertically (subsurface) through the media. Liquid collects at the bottom then flows via plastic drainage pipes to a sand filter, where chlorine solution is added for disinfection. Finally, liquids are infiltrated in an infiltration pit.

The plants visited had not been in operation for long enough to see any solids accumulation. The operating NGO did, however, note that they plan to rake off solids when required and dispose of them to land, e.g. via burial or using as a soil conditioner/compost. This extra solids treatment/disposal will incur additional costs and need a larger footprint area. As there is only one constructed wetland bed at each site, this limits flexibility in operation to cope with solids, i.e. you cannot stop feeding the plant, so it is difficult to allow a sufficient pathogen die-off period for the solids. If two beds were operated in parallel, allowance for solids storage and degradation could be included.

The constructed wetlands visited were within an excavated bund and lined with clay. Walls had been built up by 1m around the beds and were made of metal shuttering (recycled oil drums) and backfilled with earth. This design had been modified to increase resilience to flooding, and should be considered on a site-specific basis. The sites were fully enclosed with fencing and a plastic roof. The infiltration pit was made up of concrete manhole (MH) rings. Due to the terrain in the CXB camps, each site had extensive slope stability measures in place using sandbags and geotextiles.

DECENTRALISED BIOLOGICAL TREATMENT: **CONSTRUCTED WETLANDS**

PROCESS FLOW DIAGRAM AND SKETCH

Figure 15:
PFD - Constructed wetland

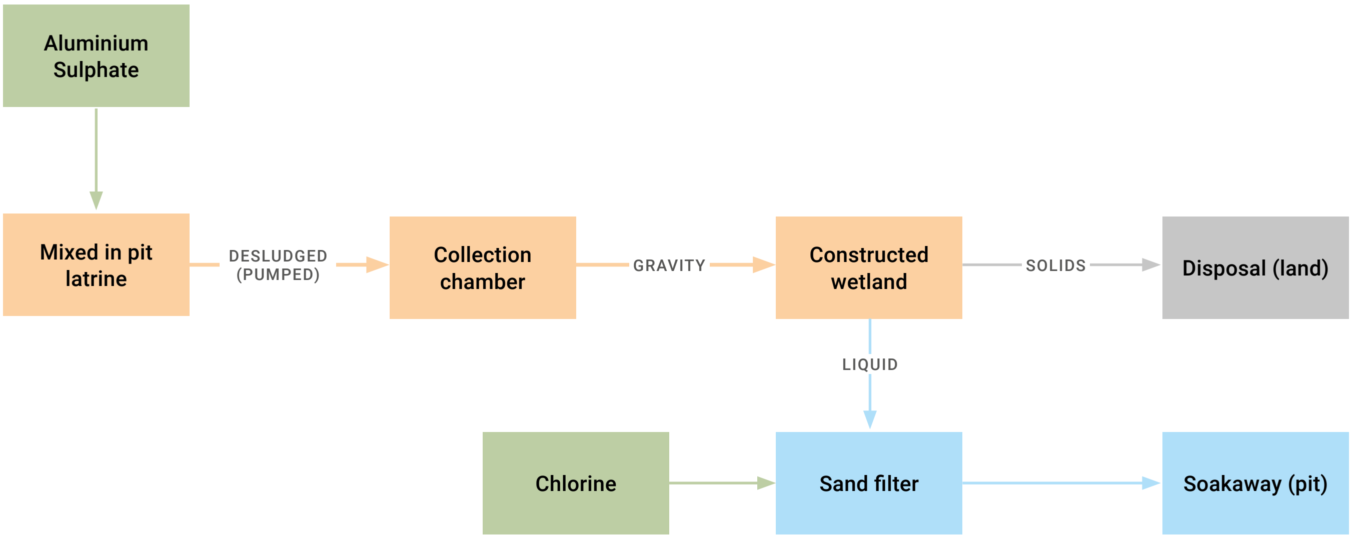
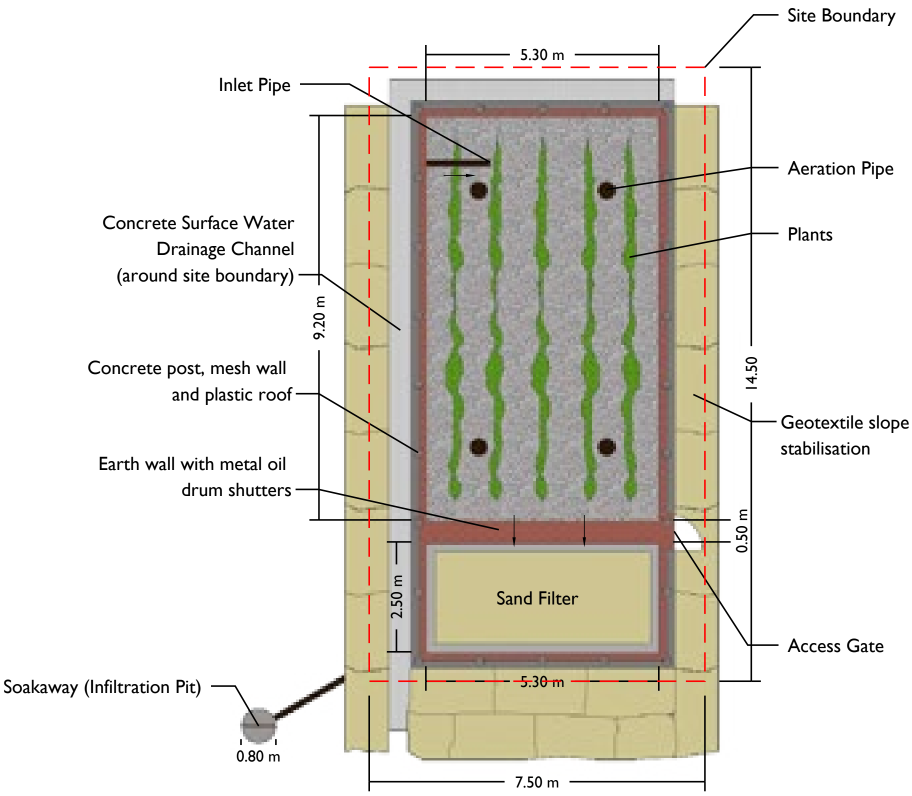
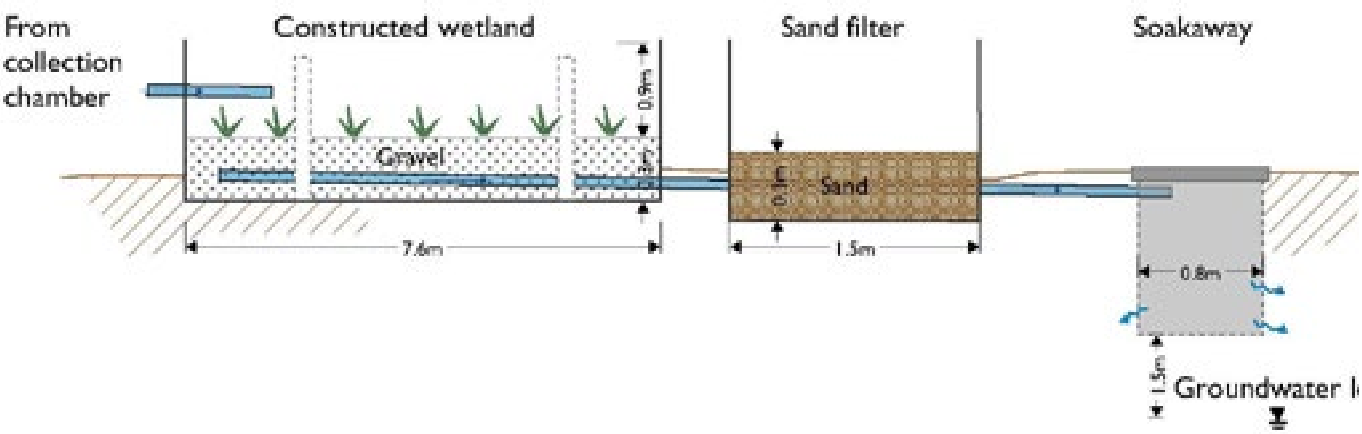


Figure 16:
Site layout plan - Constructed wetland



DECENTRALISED BIOLOGICAL TREATMENT: **CONSTRUCTED WETLANDS**

Figure 17:
Constructed Wetland typical cross section



PHOTOS

Image 13:
Constructed wetland external view

Image 14:
Constructed wetland internal view

Image 15:
Sand filter

Image 16:
Infiltration pit

DECENTRALISED BIOLOGICAL TREATMENT: **CONSTRUCTED WETLANDS**

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		- 10m³ per week (1.4 m³ per day) - Estimated as 1,000 population equivalent (PE)
	Scale/scalability	3	- Constructed wetlands have a relatively large footprint area per unit treated - The technology can be scaled up to municipal scale but area required will be limiting factor - Care is needed at to ensure good distribution of influent and avoid short circuiting - Large-scale constructed wetlands normally consist of smaller beds so as to alternate use
	Footprint area and access	4	- Sites were 60 to 80m2 total area, i.e. 56 m² per m³ treated[13] - Sites were compact and fully enclosed (fenced) - Steep terrain with only pedestrian access
	Speed of construction and setup	3	- Construction period is approximately 1 month – predominantly site stabilisation and excavation - It takes 2 months to establish plants and micro-organisms - It can take up to 6 months to achieve acceptable removal efficiencies (for BOD, pathogens and nutrients)
	Resilience to disaster	4	- CXB examples had 1m walls surrounding the plant, hence giving protection from surface water flooding - Simple excavated bunds, etc. are relatively resilient to earthquakes
TREATMENT PROCESS	**Complexity of treatment process**	3	- The treatment process is relatively simple, with the main process having 2 stages: constructed wetland followed by the sand filter with disinfection - Solids handling needs to be considered, as solids need to be periodically removed (i.e. once per year) and stored or disposed of appropriately. Limited consideration had been given to solids removal and disposal for the plants in CXB
	Treatment effectiveness	3	- No test data available for the plants visited - Meets the CXB FSM strategy 'Good' category
	Pinch point	3	- Infiltration capacity and solids storage
	Final discharge routes	3	- Solids (volume largely reduced within the constructed wetland) are stored and then disposed of via nearby land - Liquids are disinfected and infiltrated, so need to ensure the infiltration pit is adequately sized. - The effectiveness of the chlorination technique (for the liquid treatment) is not proven, so the site effluent is more likely to be classed under the 'acceptable' category.
OPERATION AND MAINTENANCE	**O&M skills requirements**	2	- Each plant was fed once per week by the latrine desludging team - Nine constructed wetlands are managed by a team of 10 people - Disinfection (chlorination) is conducted once per week via the sand filter - The constructed wetland itself has limited operational requirements as it operates by gravity - Periodic replacement of the plants is required - No experience of solids removal yet, but it is likely to be once per year (design dependent)
COSTS	**CAPEX**	5	- $11,340 for construction including labour - $8,000 per m³ treated
	OPEX	2	- $1,500 per year (excluding desludging costs but including labour, new plants and chlorine) - $2.85 per m³ treated
	WLC	2	- £36,330, assuming a plant life of 10 years and that 90% of materials need to be totally replaced once in that period

Most effective ◄ 1 ● ● ● 5 ► Least effective

Table 7:
Advantages and disadvantages of Constructed wetlands

(13) Literature suggests that for 'normal wastewater treatment' in warm climates vertical flow constructed wetlands need 1.2m² per person, i.e. for 1,000 P.E the area should be 1200m² (Hoffmann, H., Platzer, C., Winker, M., von Muench, E.: Technology review of constructed wetlands; Subsurface flow constructed wetlands for greywater and domestic wastewater treatment, Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ), Eschborn, 2011.)

6.4 DECENTRALISED BIOLOGICAL TREATMENT: **BIOGAS**

Biogas

DESCRIPTION

A number of biogas systems have been constructed by an NGO in the registered camp in CXB two or three years ago. The systems ranged in size from 2m^3 to 4m^3. The NGO had tried different material types for the biogas reactor vessel, i.e. cast in-situ concrete and prefabricated fibreglass. The structures are below ground and the plant operates under gravity.

A toilet block (typically four toilets) is connected directly to an intermediate pit below. The pit then discharges into the digestion chamber. FS digests under anaerobic conditions in the digestion chamber. Gas is piped directly from the top of the digestion chamber to a shared kitchen (constructed by the same NGO). The gas pressure is the digestion chamber is maintained by controlling the gas use (via a kitchen rota). If the gas generation process slows down, two-thirds of the solids are emptied from the digestion pit. Some are retained to ensure the biological process stays active.

Liquids flow into a hydraulic chamber and an overflow pit and then to either an infiltration or a site drain.

A Vacutug desludging pump is used to remove accumulated solids from the digestion chamber, approximately every four months. According to the NGO, disposal of solids is to a drain or composting/buried.

The site PFD and layout are shown in Figure 18 and Figure 19.

It should be noted that biogas systems visited did not provide full FS treatment, i.e. no further liquid or solids treatment and disposal. Additional solids and liquids treatment/disposal is required, incurring additional costs and footprint area.

DECENTRALISED BIOLOGICAL TREATMENT: **BIOGAS**

PROCESS FLOW DIAGRAM AND SKETCH

Figure 18:
PFD - Biogas

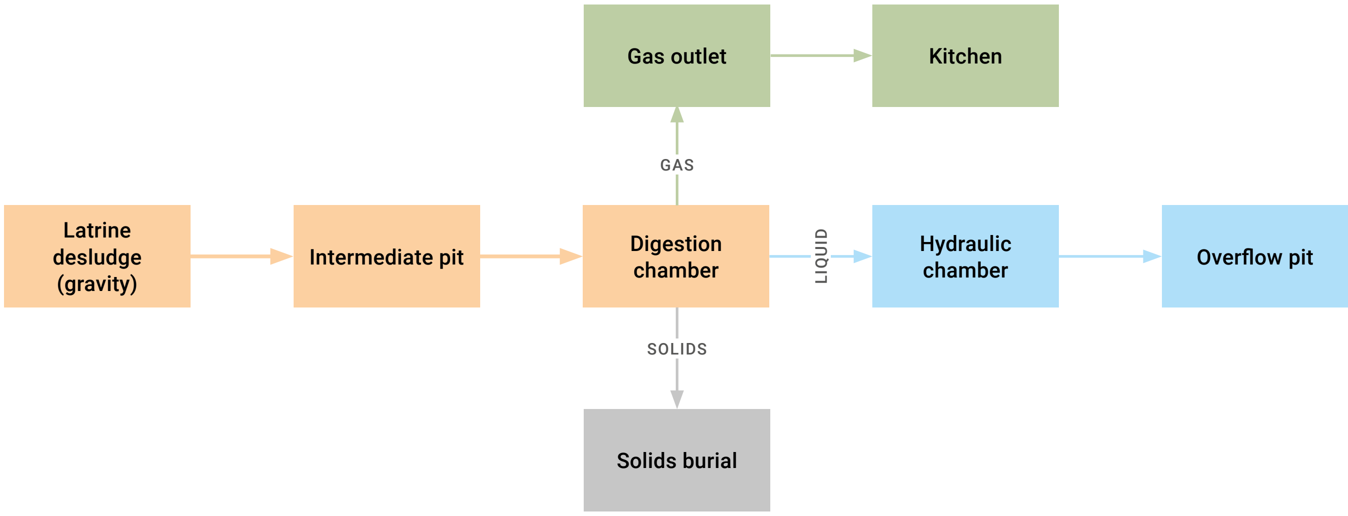
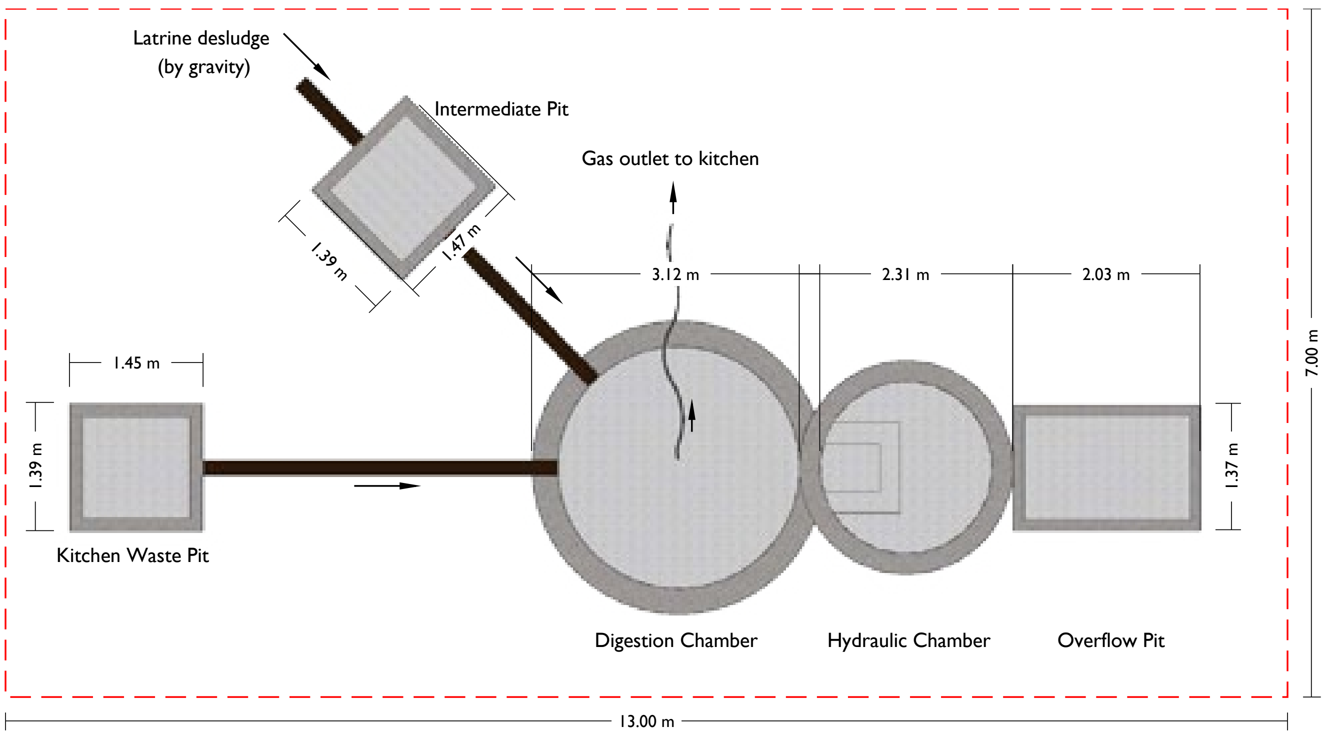


Figure 19:
Site layout plan - Biogas



DECENTRALISED BIOLOGICAL TREATMENT: **BIOGAS**

PHOTOS

Image 17:
$4m^3$ concrete biogas digester

Image 18:
Hydraulic chamber

Image 19:
Biogas kitchen

DECENTRALISED BIOLOGICAL TREATMENT: **BIOGAS**

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		- $4m^3$ per day (maximum capacity observed) - $2m^3$ per day (minimum capacity observed)
	Scale/scalability	4	- Not easily scalable for a decentralised model - Prefabricated digesters come in a variety of sizes but it is likely that the maximum $8m^3$ size would be efficient for 'household type' scale, otherwise you would need to develop a centralised type plant - Size of biogas reactor (digester) needs to be aligned with the volume of influent, i.e. toilet blocks not individual latrine - A $4m^3$ digester serves a kitchen shared by 6 families. This would need to be scaled accordingly
	Footprint area and access	1	- $36m^2$ - $9m^2$ per m^3 treated
	Speed of construction & setup	3	- Construction takes 1 to 2 months depending on if prefabricated tanks are used - It will be 40 days after initial commissioning until there is enough gas to use in the kitchen
	Resilience to disaster	4	- Tanks are below ground - Risk that gas storage tank is damaged in earthquake
TREATMENT PROCESS	**Complexity of treatment process**	3	- Plant operates with minimal staff - Relatively complex to control the biological process - Sensitive to changes in influent characteristics but experience over the last 2 to 3 years has shown there are limited changes and the system has been functioning ok
	Treatment effectiveness	4	- Initial testing (UPM) of liquid effluent shows the effluent meets the DoE liquid discharge standards except for BOD and chemical oxygen demand (COD) - For the liquid effluent, coliform levels are acceptable for human health, however, helminth eggs do not meet the required standards to protect human health - The final solids did not meet the requirements for human health for coliforms or helminths
	Pinch point	3	- Liquid storage capacity (hydraulic chamber) and disposal
	Final discharge routes	4	- Liquid is infiltrated or discharged to drains (evidence at some sites) - Solids removal is done every 4 months or when gas production slows. It is not clear where these solids are disposed of. Some solids are left in the digester to keep the process alive
OPERATION AND MAINTENANCE	**O&M Skills requirements**	3	- Two technicians doing weekly checks of 37 FSM plants (sometimes more frequent) - Cleaning crew of 13 people (also look after 37 plants) - Desludging is done every 4 to 12 months
COSTS	**CAPEX**	2	- \$3,655 treated or \$914 per m^3 treated
	OPEX	1	- \$84/yr or \$0.06 per m^3 treated
	WLC	1	- \$ 6,000, assuming a plant life of 10 years and that 40% of materials need to be to replaced once in that period. The majority of the plant is concrete, so limited replacement should be required (although it will be dependent on the context and quality)

Most effective ◂ 1 ● ● ● 5 ▸ Least effective

Table 8:
Advantages and disadvantages of biogas

Anaerobic Baffled Reactors

DESCRIPTION

An ABR is an improved septic tank with a series of baffles under which the wastewater is forced to flow. The increased contact time with the active biomass (sludge) results in improved treatment[14]. The treatment mechanisms are mechanical, i.e. settlement and filtration, and biological, i.e. anaerobic degradation (biomass on the filter media, if used, and biological degradation in an active sludge blanket at the bottom of each chamber).

ABRs do not provide a standalone sludge treatment solution. The liquid effluent requires further treatment prior to discharge to achieve pathogen kill, e.g. further filtration/polishing and/or disinfection. Solids also need to be retained for sufficient time to achieve pathogen die-off, which has implications on the cost and footprint area, or need to be disposed of appropriately, e.g. incineration or burial. This should be considered when planning an ABR system.

An NGO had recently constructed an ABR in Camp 17. The ABR has a settlement chamber followed by a baffled rector tank that facilities further solids/liquids separation through settlement. Settled solids are retained in the settler and baffled tank and removed periodically (e.g. once per year). Liquid receives further treatment by a graded gravel filter followed by a polishing pond which has an overflow to the local surface watercourse. Solids are retained within the settlement chamber and baffled tank where some digestion occurs and the volume reduces. Despite this, solids still need emptying every 6 to 12 months. The site visited was commissioned in January 2019 and there was no provision for solids storage or disposal. The NGO has time before the first solids removal to create a solids storage/burial area.

The ABR is made from reinforced concrete and brick. It is predominantly below ground level and flows by gravity from inlet to outlet.

A PFD and site layout are shown in Figure 20 and Figure 21.

(14) EAWAG Compendium of Sanitation Systems and Technologies, 2nd Edition

DECENTRALISED CHEMICAL TREATMENT: **ANAEROBIC BAFFLED REACTOR**

PROCESS FLOW DIAGRAM AND SKETCH

Figure 20:
PFD - ABR

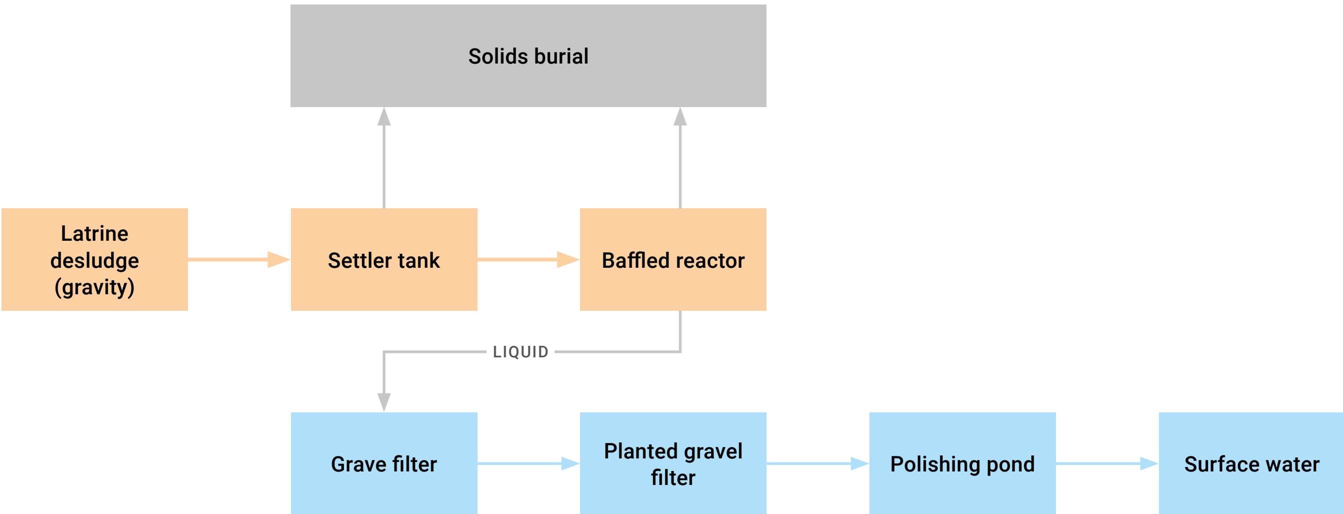
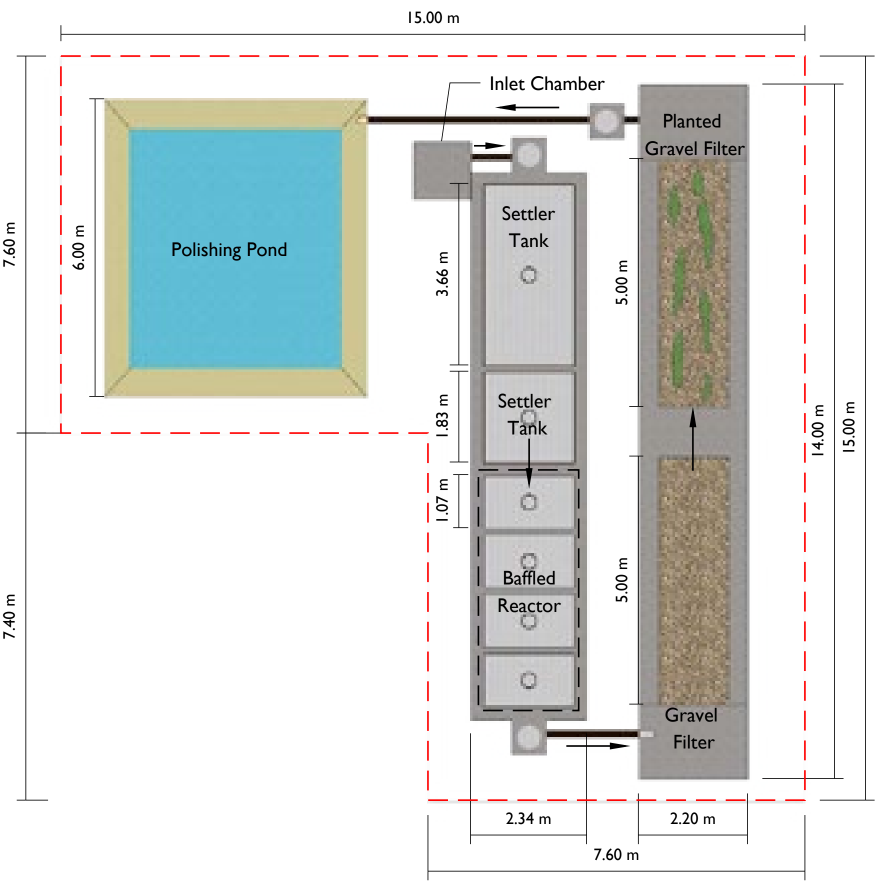


Figure 21:
Site layout plan - ABR



DECENTRALISED CHEMICAL TREATMENT: **ANAEROBIC BAFFLED REACTOR**

PHOTOS

Image 20:
ABR general site view

Image 21:
Settler and baffled tank

Image 22:
Gravel filter for liquids

Image 23:
ABR polishing pond for liquids

DECENTRALISED CHEMICAL TREATMENT: **ANAEROBIC BAFFLED REACTOR**

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		- 35m³ per day
	Scale/scalability	3	- Not modular, i.e. scale up only possible at design stage
	Footprint area and access	1	- Treatment units 185m² - 5.3m² per m³ treated - Pedestrian access
	Speed of construction and setup	3	- Excavation and concrete construction needed. Structure is relatively complicated due to internal baffles, etc.
	Resilience to disaster	4	- The liquid discharge (from the polishing pond) was located at a low level, as the ABR was below ground level. If the surrounding area floods the plant may not be able to discharge
TREATMENT PROCESS	**Complexity of treatment process**	2	- Relatively simple and robust i.e. not reliant on biological treatment - Solids/liquids separation by settlement - Anaerobic digestion of solids - Liquid filtration
	Treatment effectiveness	4	- Testing was not conducted on the plant visit but a similar plant was tested by the UPM study - The ABR tested met all the DoE liquid effluent standards except for BOD and COD - The coliform standard for protection of human health was met for both solids and liquid effluents - The (WHO 2006) helminth standard was not met for either solids or liquid effluent
	Pinch point	3	- Liquid infiltration and solids storage capacity (within and outside of the ABR)
	Final discharge routes	4	- Liquid is discharged to the polishing ponds (containing fish) where it evaporates or overflows to local surface watercourse - No solids management is in place yet. Solids removal should happen every 6 to 12 months, so a solids dewatering and burial area will be situated adjacent to the ABR
OPERATION AND MAINTENANCE	**O&M skills requirements**	2	- Very little ABR maintenance needed - Desludging is done in the camp every 4 days, so ABR is fed every 4 days - One skilled labourer may be needed every 4 days to check the site - Desludging of the ABR is required every 4 to 12 months (depending on observed accumulation rate). It is assumed will take 2 to 3 days to empty and handle solids (drying and burial)
COSTS	**CAPEX**	1	- $12,000 - $342 per m³ treated
	OPEX	1	- $800 year - $0.06 per m³ treated
	WLC	2	- £21,160, assuming a plant life of 10 years and that 40% of materials need to be to replaced once in that period. The majority of the ABR is concrete so shouldn't need replacing

Most effective ◂ 1 ● ● ● 5 ▸ Least effective

Table 9:
Advantages and disadvantages of ABRs

6.6 DECENTRALISED CHEMICAL TREATMENT: **LIME**

Lime

DESCRIPTION

Seven lime treatment sites were visited across the camps, all of which were decentralised chemical treatment plants. These were operated by five different NGOs, with a single NGO managing each site. Five systems are described in the following sections and summarised in Table 10.

Lime treatment achieves pathogen reduction by mixing sludge with hydrated lime (calcium hydroxide) in order to raise the pH to over 12 for 30 minutes to an hour. Each NGO had tried to optimise the lime dose to achieve this, and each had a slightly different method and infrastructure. A PFD of each site and a site layout are shown in Figure 18 to Figure 27.

The lime dosing rate was generally 20kg per m^3 of FS, which is higher than the rate literature suggests (by approximately two or three times[15]). This is thought to be due to the quality of the lime powder (calcium hydroxide) used and over-dosing to ensure no pathogen regrowth. Lime powder is the highest OPEX item, so refining this dose will reduce OPEX.

The management of solid and liquid also differed slightly between sites. Some (good and bad) features of each are noted below.

Lime Site 1 used an incinerator to dispose of solids. This ensured safe disposal of the solids and reduced the volume for final disposal i.e. to ash. This is important for public health as (UPM) testing showed that helminth eggs were still present (with levels above the WHO reuse standards) in the dried solids. Adequate space for solids storage, downstream of the drying bed was provided in an area next to the incinerator. Liquid was drained (from the dewatering and drying beds) to an infiltration pond, however, due to the large volume of liquids and (potential) impermeability of the local soil, infiltration was limited. This had led to an open pond close to surface water and local residents, creating a potential public health risk. UPM testing showed that the coliform level in the liquid effluent met the WHO standards but that helminth eggs were still present. Infiltration testing of the soil should be conducted during site planning to ensure an adequate area is provided for liquid disposal. This should ideally be in infiltration trenches, i.e. below ground surface, to limit exposure.

Sites 2, 3 and 4 dried solids and then disposed of them via the land, i.e. either buried or used locally as soil conditioner/compost. Solids should be stored for a minimum of 24 months ahead of reuse to ensure the required reduction in helminth eggs. It was not clear that this was being achieved for Sites 2, 3 and 4.

Testing by UPM showed that Site 4 achieved WHO (reuse) standards for both final liquid and solids. The sludge for this site came from a larger wastewater treatment site (aeration site) operated by the same NGO. Some pathogen reduction will have been achieved in the wastewater treatment and then the lime treatment reduces this further and prevents any pathogen regrowth. This site diluted the lime powder in water (1:1) ahead of mixing with FS in 50 litre barrels. This will achieve good mixing and contact of the FS with the Lime, again ensuring pathogen reduction.

Site 5 was enclosed in concrete/brick tanks limiting the workers' pathogen exposure. It had adequate solids storage capacity (in pits) to store solids for two years ahead of disposal/reuse. Liquids were disposed to an infiltration trench. This ensured safe disposal of the solids and liquid and limited the exposure of people to the final products.

(15) Compared to EAWAG Compendium of Sanitation Systems and Technologies, and MetCalf and Eddy Wastewater Engineering.

DECENTRALISED CHEMICAL TREATMENT: **LIME**

Sites 2 and 3 had a lower footprint area per m^3 treated than the other lime sites. This was because they used rectangular shaped tanks/lagoons that were laid out efficiently, i.e. in process flow order and in several parallel streams with shared access paths.

Sites had a similar OPEX with Site 3 the highest, as they had not yet optimised the lime dose. This also meant Site 3 has the highest WLC.

It should be noted that measurement methods for lime lagoon/chambers are likely flawed. This is due to samples often being taken from the top of mixing tanks and not capturing any inadequacies in the mixing in the lower portion of the tanks. The likelihood of inadequate mixing in lime chambers is a disadvantage of the technology and a challenging one to detect because of the difficulty of measuring the lower parts of the mixing chamber.

Summary of Lime treatment sites

NAME IN THIS REPORT	TECHNOLOGY	BRIEF DESCRIPTION
Lime 1	Lagoon Lime treatment with dewatering operated by NGO X	Lime powder mixed with FS in excavated ponds or lagoons, followed by dewatering beds, liquid treatment and solids (cake) incineration
Lime 2	Lagoon Lime treatment with dewatering operated by NGO Y	Lime powder mixed with FS in excavated ponds or lagoons, followed by dewatering beds, liquid treatment infiltration and solids storage
Lime 3	Lagoon Lime treatment with dewatering bed operated by NGO Z	Lime powder mixed with FS in concrete tanks, followed by dewatering beds, liquid treatment infiltration and solids storage
Lime 4	In barrel treatment with dewatering beds	Lime solution mixed in 50 litre barrels, followed by dewatering beds, liquid treatment infiltration and solids drying and storage
Lime 5	3-tank lime system	A three-tank system operated in series. Lime powder mixed at inlet, FS retained for three days in each tank, followed by liquid infiltration and solids storage

Table 10:
Summary of Lime treatment sites

DECENTRALISED CHEMICAL TREATMENT: **LIME**

PROCESS FLOW DIAGRAM AND SITE LAYOUT PLANS - **LIME 1**

Figure 22:
PFD - Lime 1

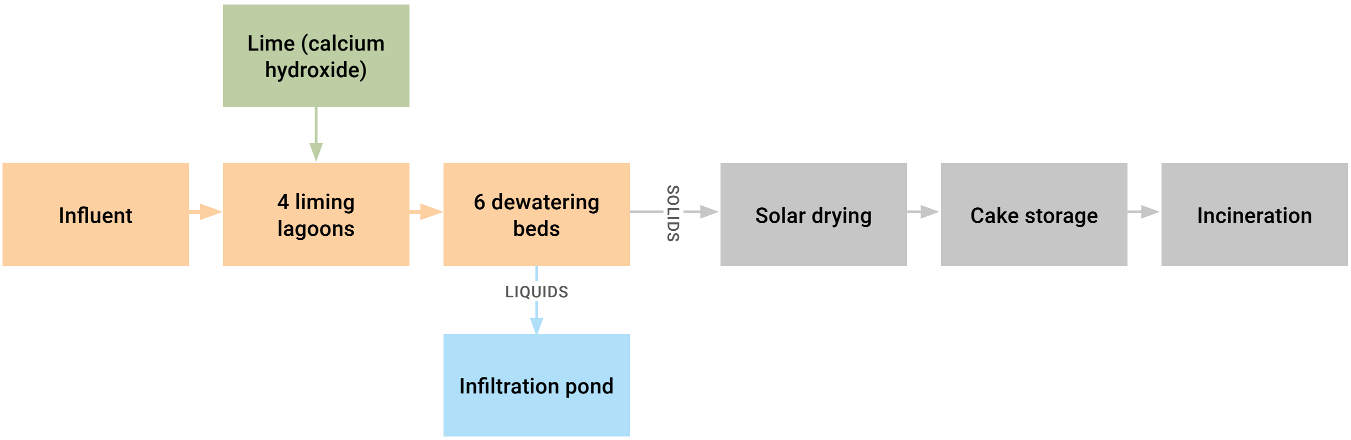
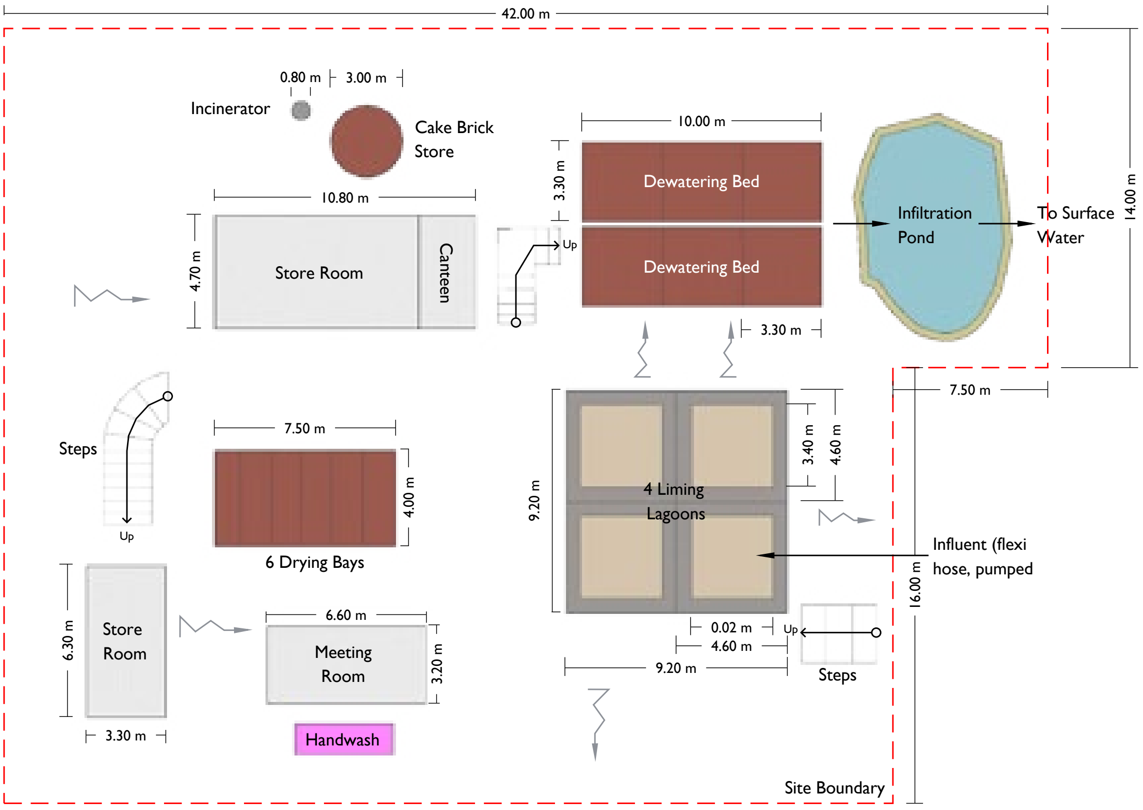


Figure 23:
Site layout plan - Lime 1



DECENTRALISED CHEMICAL TREATMENT: **LIME**

PHOTOS - LIME 1

Image 24:
Lime 1 - Lime mixing lagoon (No.4)

Image 25:
Lime 1 - Dewatering bed

Image 26:
Lime 1 - Drying bays

Image 27:
Lime 1 - Solids (cake) storage and incineration

DECENTRALISED CHEMICAL TREATMENT: **LIME**

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA - LIME 1

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		- 5.7m³ per day
	Scale/scalability	2	- Easily replicable, simple excavated lagoons - Scale up could be achieved by installing additional treatment units in parallel. However, this site must have space for increasing capacity
	Footprint area and access	4	- Treatment units 300m² - 53m² per m³ treated - Pedestrian access
	Speed of construction and setup	2	- Commissioning is fast, so good for rapid response to emergency. Chemical treatment does not require time to activate treatment, i.e. no biological growth stage - One month to construct with 20 manual labourers. No large civil structures required
	Resilience to disaster	1	- Elevated site so flood resistant. No large civil structures so relatively earthquake resistant.
TREATMENT PROCESS	**Complexity of treatment process**	3	- Simple process and the lime dose is quick to monitor and adjust. - Two main treatment stages, i.e. mixing and dewatering, followed by solids drying and incineration and liquid infiltration - Drying stage of solids will impact efficiency of incineration stage
	Treatment effectiveness	2	- Classed as 'acceptable' under CXB FSM strategy - UPM data show WHO (reuse) standards are met for coliform (E.coli), but helminths or helminth eggs are still present - DoE COD and BOD standards are not met
	Pinch point	3	- Dewatering bed area - Liquid disposal due to infiltration capacity
	Final discharge routes	2	- Incineration of solids is a good disposal route. Heat could be used, e.g. for heating water or drying sludge, but this would add complexity to the operation
OPERATION AND MAINTENANCE	**O&M skills requirements**	4	- FSM plant requires 6 people for 3 days plus 1 security guard and 1 engineer every day
COSTS	**CAPEX**	2	- $4,270, i.e. relatively low due to no large civil structures and use of local materials (bamboo). - $750 per m³ treated
	OPEX	4	- Approximately $21,350 per year including labour, fuel for pumping and Lime. - $10 per m³ treated
	WLC	5	- $221,170 - Bamboo superstructures have 2 to 3 years of life. This has been accounted for in the CAPEX repeats - Assumed 80% of materials need to be totally replaced once in every 10-year period

Most effective ◀ 1 ● ● ● 5 ▶ Least effective

Table 11:
Advantages and disadvantages of lime (1)

PROCESS FLOW DIAGRAM AND SITE LAYOUT PLANS - **LIME 2**

Figure 24:
PFD - Lime 2

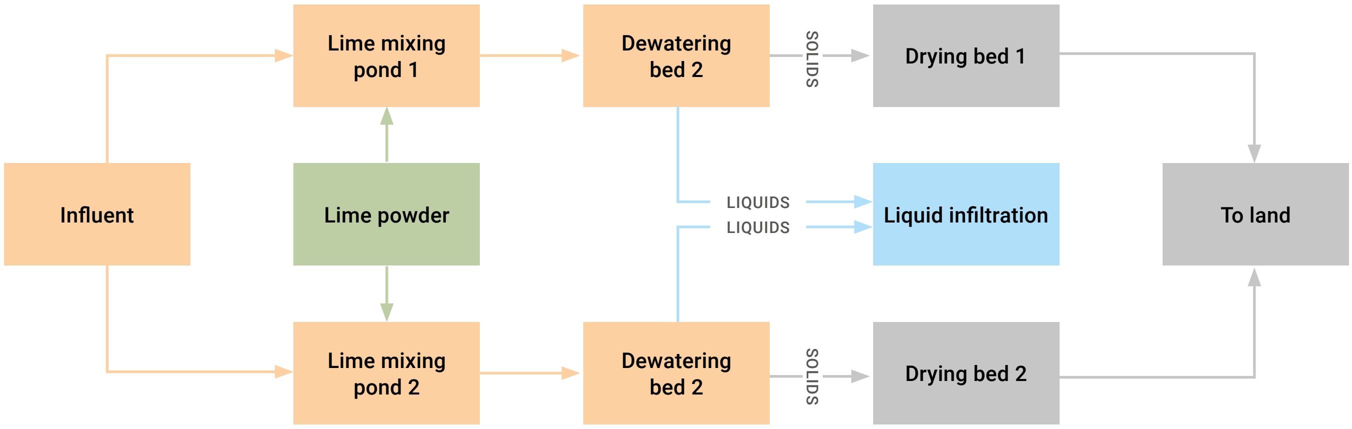
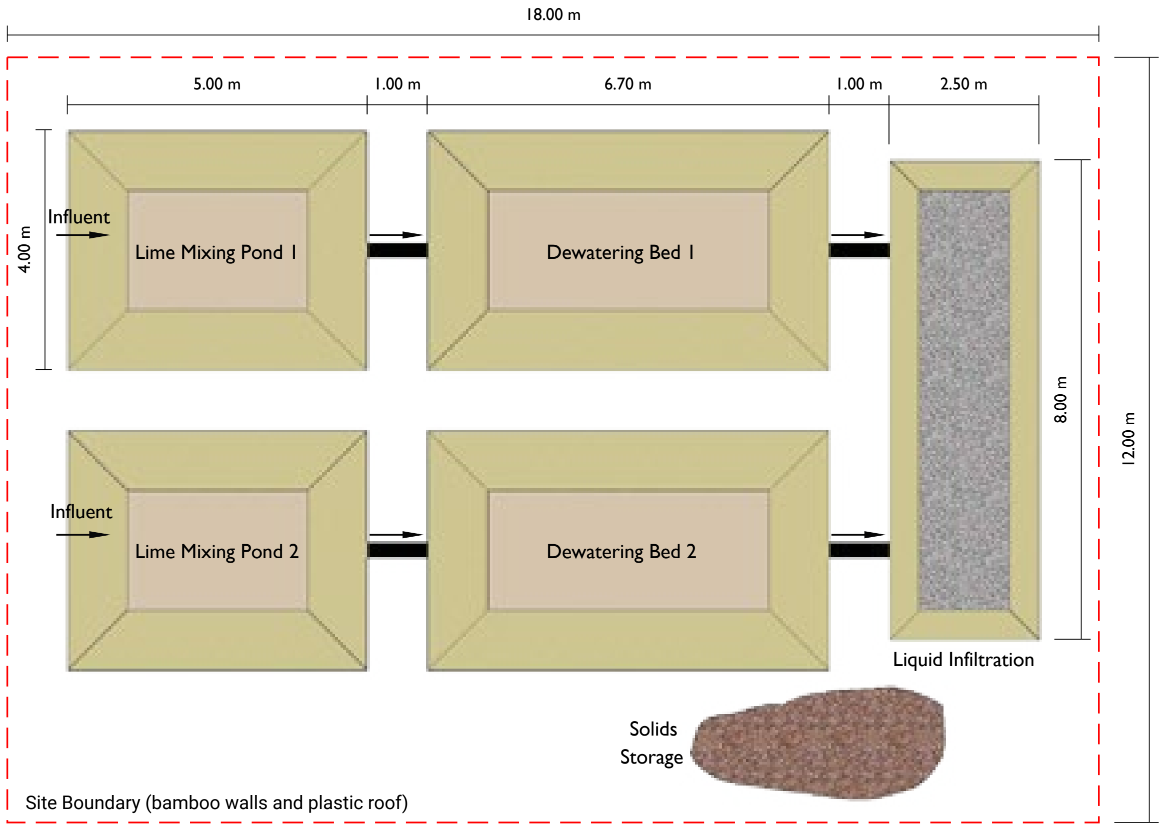


Figure 25:
Site layout plan - Lime 2



PHOTOS - LIME 2

Image 28:
Lime 2 - Lime mixing lagoon

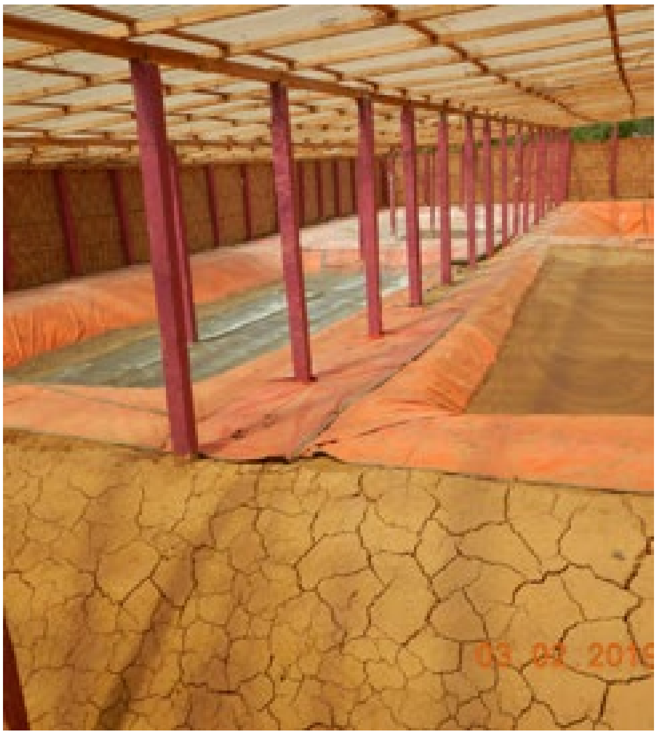


Image 29:
Lime 2 - Dewatering beds

Image 30:
Lime 2 - Liquid infiltration

Image 31:
Lime 2 - Solids (cake) storage outside FSM plant

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA - LIME 2

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		- $11m^3$ per day
	Scale / scalability	2	- Easily replicable simple excavated lagoons - Scale up could be achieved by installing additional treatment units in parallel. However, this site must have space for increasing capacity
	Footprint area and access	2	- Treatment units $200m^2$ - $18m^2$ per m^3 treated - Pedestrian and vehicle access
	Speed of construction and setup	1	- Commissioning is fast, so good for rapid response to an emergency. Chemical treatment does not require time to activate, i.e. no biological growth stage - Construction takes 1 month
	Resilience to disaster	2	- No large civil structures so relatively earthquake resistant - No slope stabilisation in ponds, so ponds may be susceptible to earthquake damage
TREATMENT PROCESS	**Complexity of treatment process**	3	- Simple process, only 2 stages to manage plus solids and liquids disposal, and the lime dose is quick to monitor and adjust - Process units laid out in flow order making it simple to understand and operate
	Treatment effectiveness	2	- Classed as 'acceptable' under CXB FSM strategy - No test data available - Solids storage and handling, i.e. in open space, poses public health risk and exposure to vectors
	Pinch point	3	- Drying/dewatering area
	Final discharge routes	4	- Solids storage and disposal - needs more space to be safely managed
OPERATION AND MAINTENANCE	**O&M skills requirements**	4	- FSM plant requires 2 to 3 'unskilled' people per day to mix lime and remove solids from the dewatering beds - Two engineers required to cover two plants
COSTS	**CAPEX**	2	- Approximately $10,710 - $975 per m^3 treated
	OPEX	3	- Approximately $37,975 per year including labour, fuel for pumping and Lime - $9 per m^3 treated
	WLC	5	- $396,870 - Superstructure has some bamboo which will need replacing every 2 to 3 years - Assumed 60% of materials need to be totally replaced once in every 10 year period

Most effective ◀ 1 ● ● ● 5 ▶ Least effective

Table 12:
Advantages and disadvantages of lime (2)

DECENTRALISED CHEMICAL TREATMENT: **LIME**

PROCESS FLOW DIAGRAM AND SITE LAYOUT PLANS - **LIME 3**

Figure 26:
PFD - Lime 3

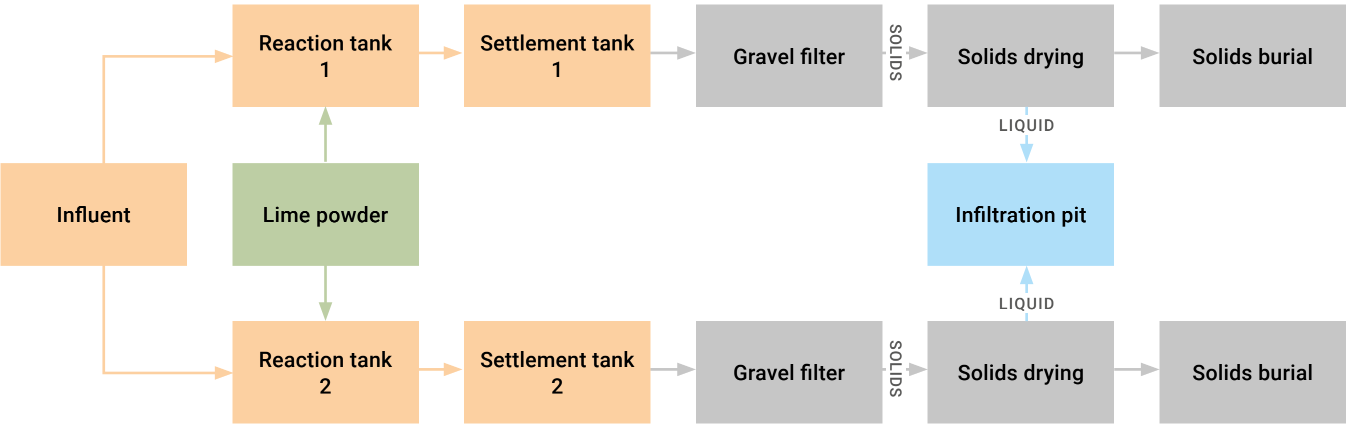
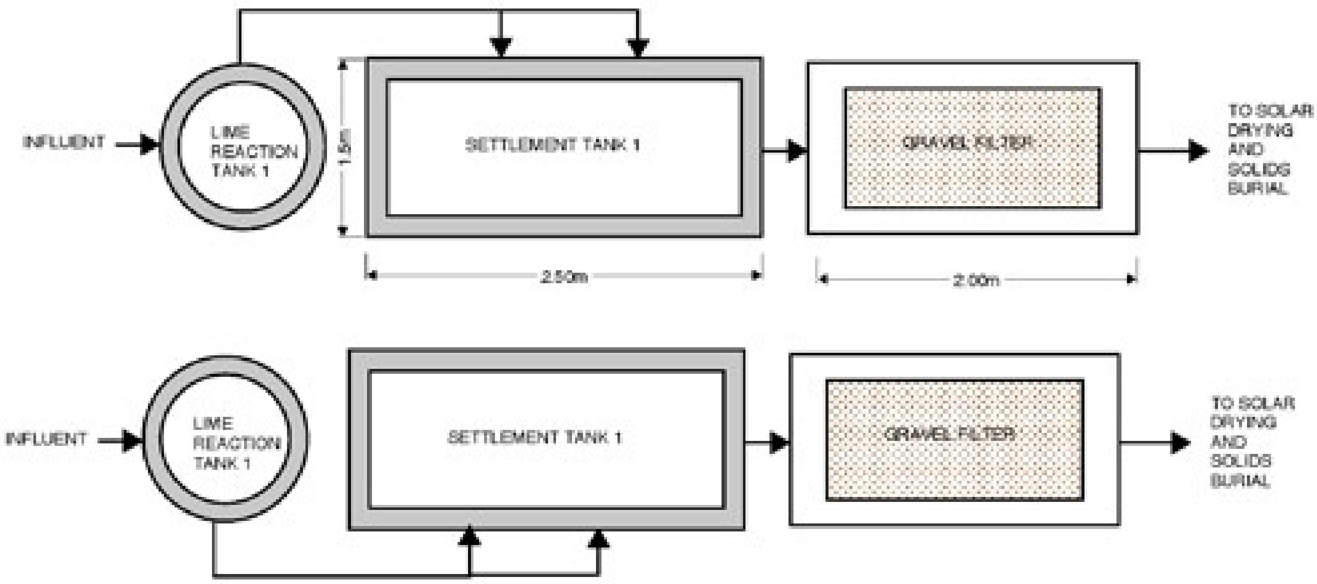


Figure 27:
Site layout plan - Lime 3



DECENTRALISED CHEMICAL TREATMENT: **LIME**

PHOTOS - LIME 3

Image 32:
Lime 3 - Lime mixing/reactor tanks

Image 33:
Lime 3 - Settlement tank

Image 34:
Lime 3 - Gravel filter/dewatering bed

Image 35:
Solids storage area (under construction)

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA - LIME 3

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	Capacity		- 3.7m³ per day
	Scale/scalability	3	- Scale up could be achieved by installing treatment units in parallel - Structures are concrete so are less simple to scale up than excavated lagoons
	Footprint area and access	3	- Treatment units are 130m² - 35m² per m³ treated - Pedestrian access
	Speed of construction and setup	2	- Commissioning is fast so good for rapid response to an emergency. Chemical treatment does not require time to activate, i.e. no biological growth stage - 2 to 3 months for construction
	Resilience to disaster	3	- Settlement tanks are below ground level so may be susceptible to flooding; however, the site location in this case is not in an area known to flood
TREATMENT PROCESS	Complexity of treatment process	3	- Simple process with only three stages plus solids and liquids disposal - Process units laid out in flow order making it simple to understand and operate
	Treatment effectiveness	2	- Classed as 'acceptable' under CXB FSM strategy - No test data available - Liquid infiltration and solids burial control presents exposure to pathogens risk
	Pinch point	3	- TBC, plant had just started operating, but the solids drying area looked small
	Final discharge routes	3	- Liquids are infiltrated - but infiltration pit is on a steep slope - Solids handling (drying) was under construction
OPERATION AND MAINTENANCE	O&M skills requirements	4	- FSM plant requires 4 'unskilled' people every 3 days - Also requires 2 supervisors per camp
COSTS	CAPEX	3	- $7,435 - $2,000 per m³ treated
	OPEX	5	- Approximately $41,270 per year - Relatively high due to cost of lime and lime dosing not yet optimised - $30 per m³ treated
	WLC	5	- $420,881 - Concrete structures have a 20yr+ lifespan so good WLC/limited CAPEX repeats - Assumed 10% of materials need to be totally replaced once in a 10-year period

Most effective ◀ 1 ● ● ● 5 ▶ Least effective

Table 13:
Advantages and disadvantages of lime (3)

PROCESS FLOW DIAGRAM AND SITE LAYOUT PLANS - LIME 4

Figure 28:
PFD - Lime 4

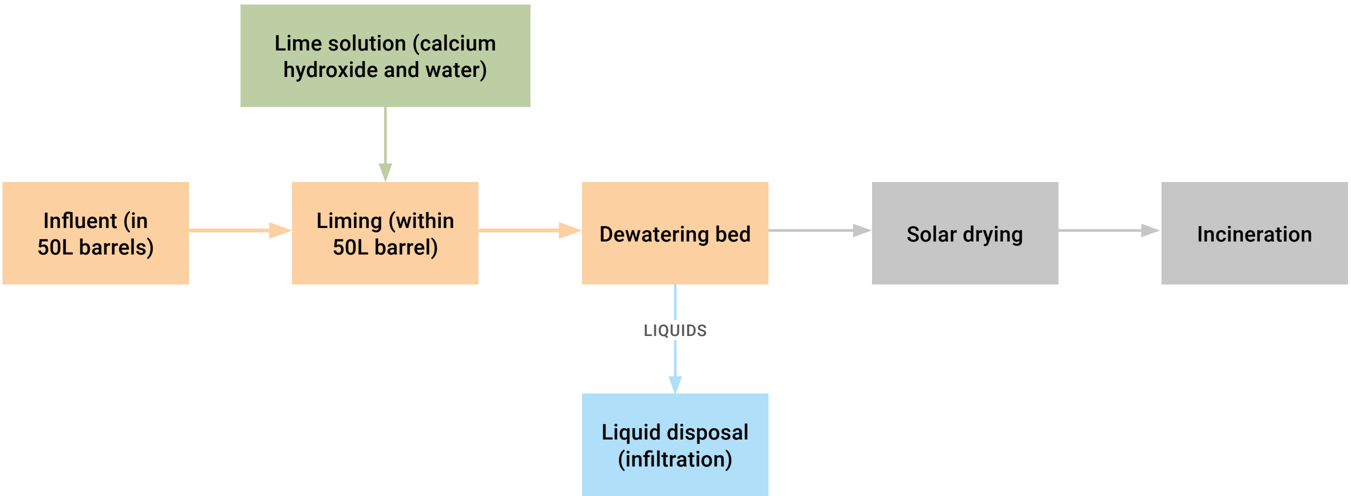
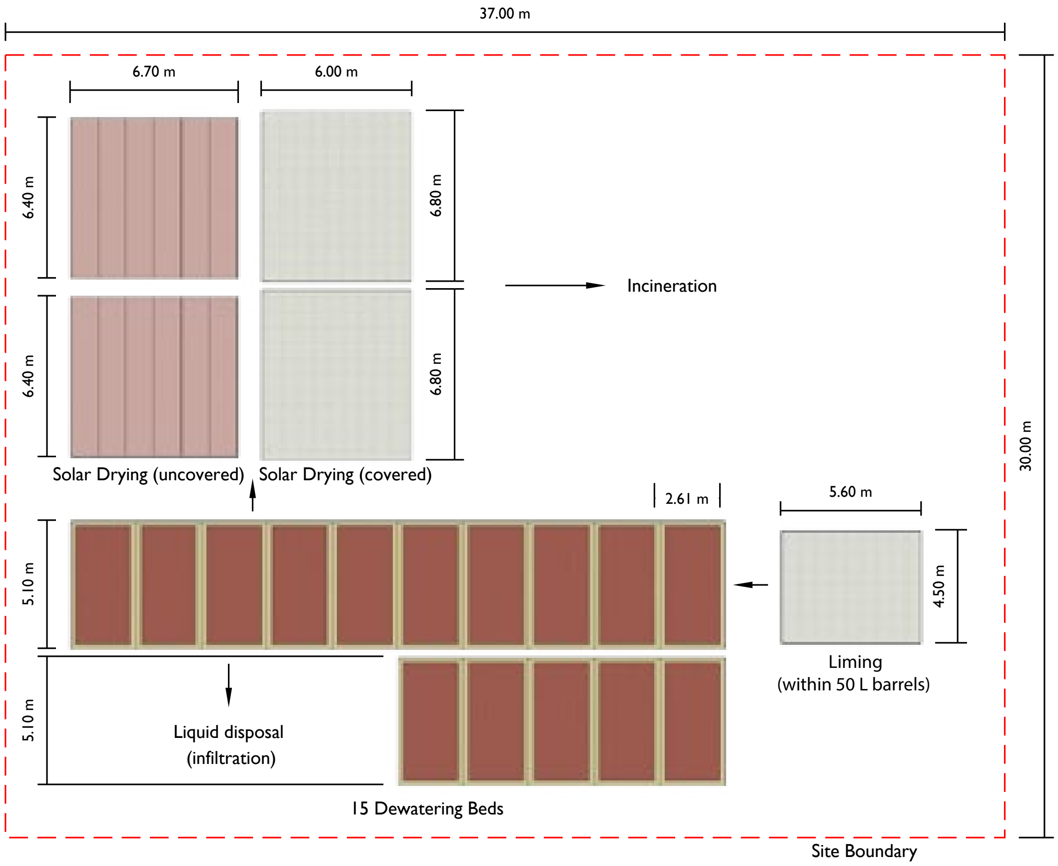


Figure 29:
Site layout plan - Lime 4



PHOTOS - LIME 4

Image 36:
Lime 4 - Lime mixing area

Image 37:
Lime 4 - Drying racks

Image 38:
Dewatering bed

DECENTRALISED CHEMICAL TREATMENT: **LIME**

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA - LIME 4

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		- 4m³ per day
	Scale / scalability	2	- Scale up of 'in-barrel' mixing is simple and will not require a much bigger area. Barrels can also be stacked - Dewatering can be scaled up with additional beds (simply excavated soil)
	Footprint area and access	3	- Treatment units are 150m² - 38m² per m³ treated - Pedestrian access
	Speed of construction and setup	1	- Commissioning is fast, so good for rapid response to an emergency. Chemical treatment does not require time to activate, i.e. no biological growth stage - 1 month to construct
	Resilience to disaster	2	- No large civil structures so (relatively) resistant to earthquake - Dewatering beds are at ground level i.e. excavated with no edge built up so susceptible to flooding
TREATMENT PROCESS	**Complexity of treatment process**	3	- Mixing in barrels allows stringent quality control and is simple to get the lime dose correct or to adjust it - Simple two-stage process followed by solids disposal
	Treatment effectiveness	2	- Classed as 'acceptable' under CXB FSM strategy - (UPM) testing had showed that WHO (reuse) standards were achieved for both final liquid and solids. - The majority of the DoE standards are met with the exception of COD and BOD
	Pinch point	3	- Dewatering bed area, especially in the wet season when this process extends to 5 to 8 days
	Final discharge routes	2	- Solids are buried or incinerated so disposed of safely
OPERATION AND MAINTENANCE	**O&M skills requirements**	4	- Staff can be easily trained to operate and maintain FSM site - 1 supervisor, 2 guards, 2 volunteers ('unskilled')
COSTS	**CAPEX**	3	- $6,962 - $1,740 per m³ treated
	OPEX	4	- Approximately $22,118 per year or $15 per m³ treated
	The whole life costs (WLC)	4	- $238,590 - All bamboo superstructures have a 2 to 3 year life - Assumed all materials will need to be totally replaced once in a 10-year period and the bamboo structures replaced more than once

Most effective ◀ 1 ● ● ● 5 ▶ Least effective

Table 14:
Advantages and disadvantages of lime (4)

DECENTRALISED CHEMICAL TREATMENT: **LIME**

PROCESS FLOW DIAGRAM AND SITE LAYOUT PLANS - **LIME 5**

Figure 30:
PFD - Lime 5

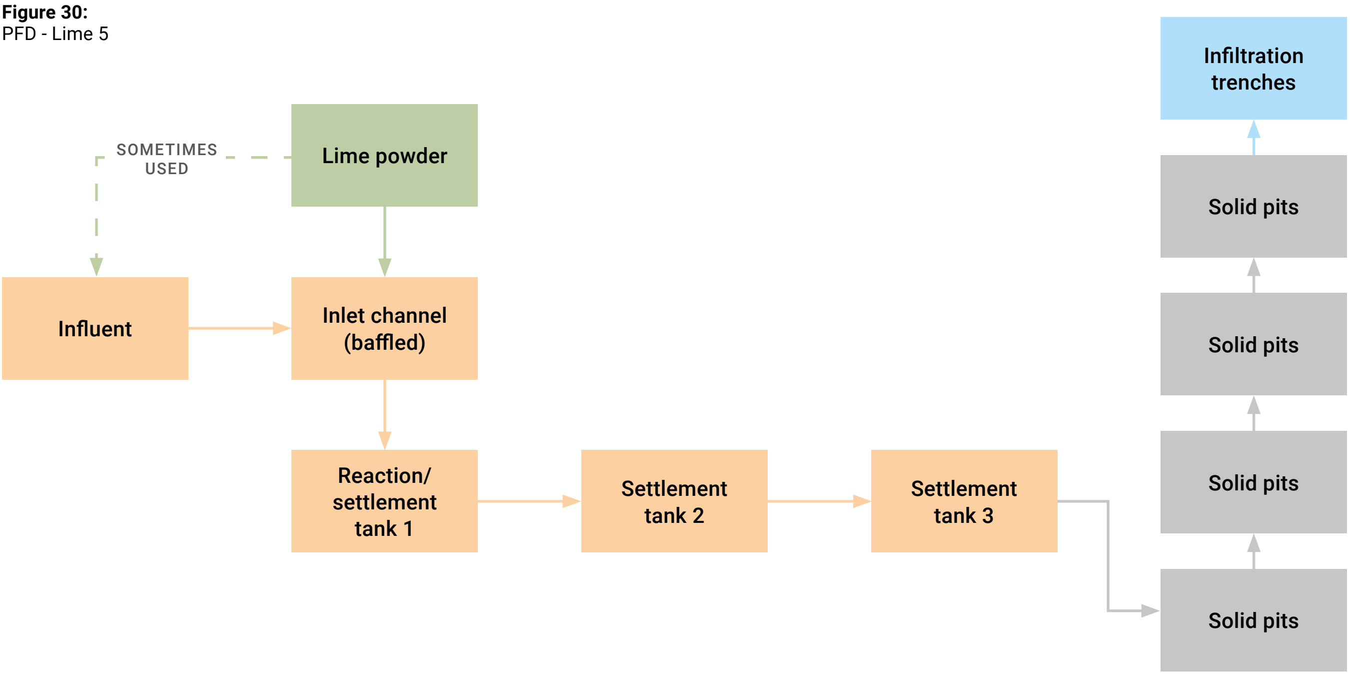
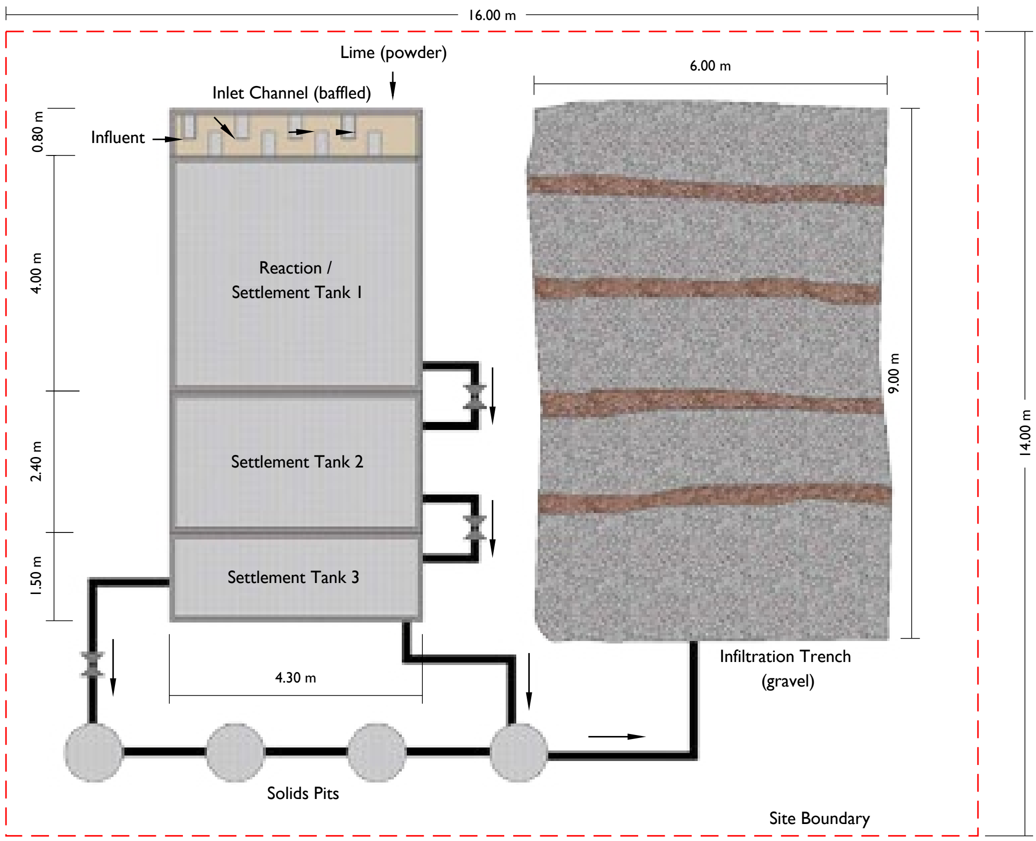


Figure 31:
Site layout plan - Lime 5



DECENTRALISED CHEMICAL TREATMENT: **LIME**

PHOTOS - LIME 5

Image 39:
Lime 5 - Inlet and lime mixing point

Image 40:
Lime 5 - Lime holding tank (1 of 3)

Image 41:
Lime 5 - Solids storage pits

Image 42:
Lime 5 - Liquid infiltration trenches

DECENTRALISED CHEMICAL TREATMENT: **LIME**

Image 43:
Lime 5 - General view

DECENTRALISED CHEMICAL TREATMENT: **LIME**

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA - LIME 5

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		- $2.7m^3$ per day
	Scale/scalability	4	- Concrete/brick structure of set dimensions. Size increase could affect the lime mixing efficiency and increase risk of solids building up in a (difficult to access) tank
	Footprint area and access	3	- Treatment units are $110m^2$ - $41m^2$ per m^3 treated - Pedestrian access
	Speed of construction and setup	1	- Commissioning is fast, so good for rapid response to an emergency. Chemical treatment does not require time to activate, i.e. no biological growth stage - 2 months to construct 14 plants, or approximately 2 weeks to construct one
	Resilience to disaster	2	- Raised above flood level and concrete/brick structures that are resistant to flooding - Civil structures that are rigid may be susceptible to earthquake damage
TREATMENT PROCESS	**Complexity of treatment process**	3	- Simple process as lime dose is quick to monitor and adjust. - Limited operator intervention needed e.g. due to mixing achieved as a function of discharging sludge - At the inlet channel, flow control valves need operating every 3 days - Solids and liquids separated by gravity and flow to the disposal site
	Treatment effectiveness	2	- Classed as 'acceptable' under CXB FSM strategy - Aiming for pH of 11 to 11.5 (dip a bucket to first chamber and check pH). No test data available
	Pinch point	3	- Infiltration capacity for liquid disposal - space available for infiltration trench
	Final discharge routes	2	- Contained, so good controls on vectors and exposure
OPERATION AND MAINTENANCE	**O&M skills requirements**	3	- Unskilled labour with 1 engineer per camp to supervise - Low labour requirement (1 person every 3 days)
COSTS	**CAPEX**	3	- $4,235 - $1,570 per m^3 treated
	OPEX	4	- Approximately $10,000 per year due to low labour cost (1 person every 3 days) - $10 per m^3 treated
	WLC	4	- $105,600 assuming 10% of materials need to be totally replaced once in a 10-year period - Civil structures are brick and concrete so have a 10yr+ lifespan, i.e. no CAPEX repeats

Most effective ◀ 1 ● ● ● 5 ▶ Least effective

Table 15:
Advantages and disadvantages of lime (5)

6.7 CENTRALISED BIOLOGICAL TREATMENT: **ANAEROBIC LAGOONS**

Anaerobic Lagoons

DESCRIPTION

Anaerobic lagoons are centralised biological FSM plants, in this case located in Camp 4 and constructed and operated by one NGO. The FSM plant visited has a capacity of 120m^3 per day[16] and takes the majority of the FS from camp 4 plus some from other areas and other NGOs. The FSM PFD and layout are shown in Figure 28 and Figure 29.

FS is delivered to the inlet via two tankers (each with 5,000 litre capacity) or via a series of pumps and intermediate tanks with a final line of gravity to the inlet screens. No limed sludge is accepted at the site in order to protect the biological process.

The incoming sludge is screened and enters one of two covered lagoons, each 1,400m^3, operated in parallel. The covers maintain anaerobic conditions within the lagoons. There are biogas outlets in the covers to allow gas to be collected and stored/used (gas storage to be constructed later in phase 2). There is a liquid overflow at the top of the lagoons and solids outlet pipes, with valve controls, from the base of the lagoons.

The main treatment mechanism in the lagoons is solid/liquid separation by settlement. The lagoon retention time is approximately 130 days (based on information from BORDA) which allows settlement, the accumulated solids to digest under the anaerobic conditions and pathogen die-off.

The liquid overflows to a sedimentation tank with a bristle filter (two operated in parallel) and then goes on to the polishing pond. The final effluent is discharged via a meandering outlet channel to a local surface watercourse. This allows time and sufficient surface area for effluent to oxygenate prior to discharge.

Solids storage within the lagoons is sized so that solids can be held for 1.5 years (based on assumed influent sludge characteristics).

When required, the solids will be emptied on to a planted drying bed (to be constructed under phase 2) with drained liquid returned to the liquid treatment stream. The drying bed will allow storage of solids for approximately one year, which will allow for stabilisation and pathogen die-off. After this, solids should be safe for reuse as compost/soil conditioner or buried.

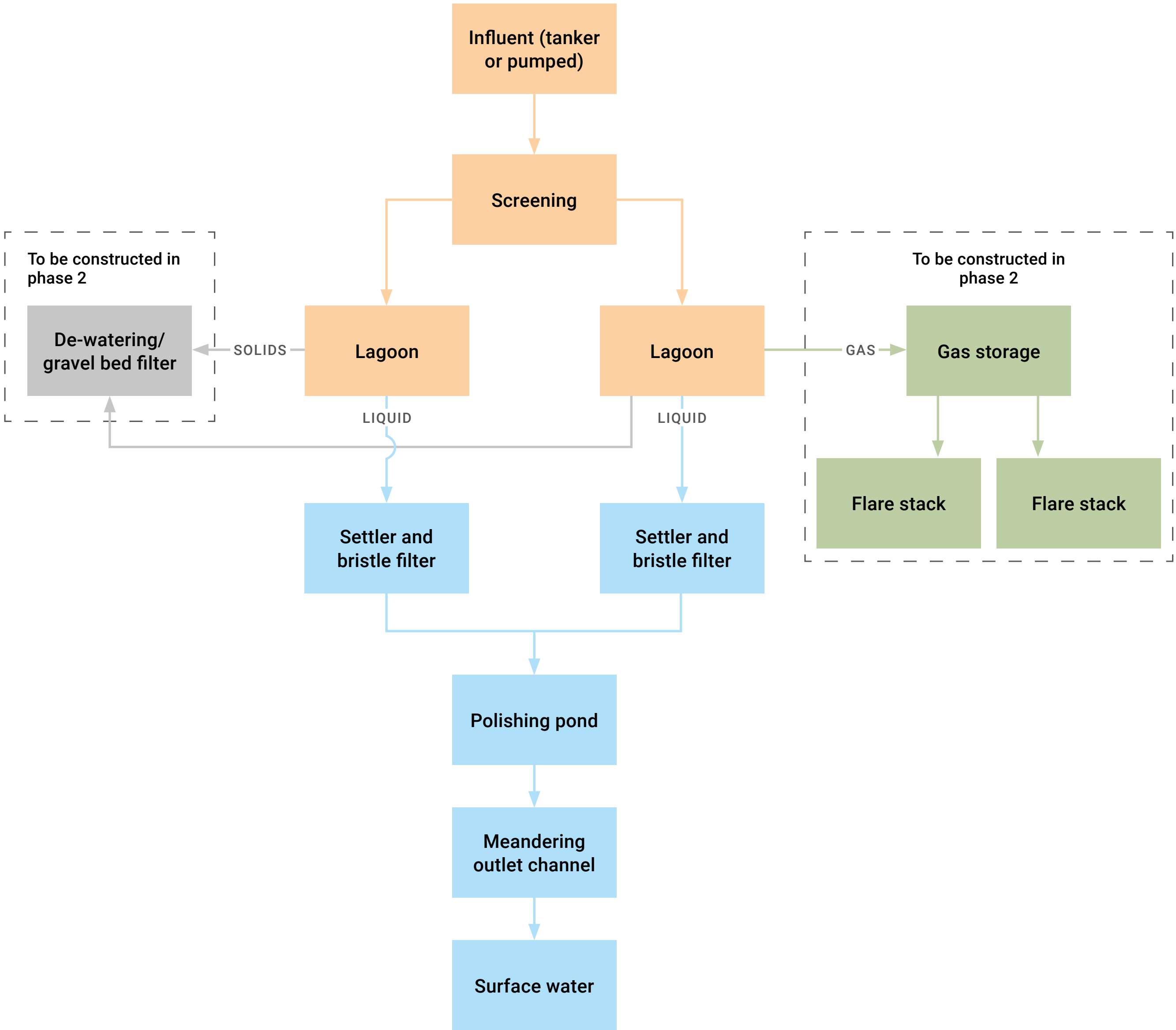
During the site visit, the lagoons had only recently been commissioned, therefore only limited information was available on the treatment effectiveness and operational issues.

A PFD and site layout plan are shown in Figure 32 and Figure 33.

(16) The plant has been designed based on the solids treatment requirements i.e. the solids loading rate and storage capacity (to be constructed under phase 2) allows for up to 120m^3 per day. This means that phase 1 of the plant (solids liquid separation and liquid treatment) has some spare capacity in addition to 120m^3 per day.

PROCESS FLOW DIAGRAM

Figure 32:
PFD - Anaerobic lagoons



CENTRALISED BIOLOGICAL TREATMENT: **ANAEROBIC LAGOONS**

SITE LAYOUT PLANS

Figure 33:
Site layout plan - Anaerobic lagoons

CENTRALISED BIOLOGICAL TREATMENT: **ANAEROBIC LAGOONS**

PHOTOS

Image 44:
Sludge tanker

Image 45:
Inlet screens

Image 46:
Anaerobic lagoon

CENTRALISED BIOLOGICAL TREATMENT: **ANAEROBIC LAGOONS**

PHOTOS

Image 47:
Settler with bristle filter

Image 48:
Meandering outlet channel

Image 49:
Polishing pond

CENTRALISED BIOLOGICAL TREATMENT: **ANAEROBIC LAGOONS**

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		- 120m³ per day
	Scale/scalability	5	- Centralised treatment process, with scale up possible by adding new treatment units (e.g. anaerobic lagoons) in parallel - Expansion space has been allocated for an additional 3 anaerobic lagoons (same size as existing) - Smaller anaerobic lagoons could be constructed according to the context, but the minimum size still provides a 'centralised system' - A key advantage of anaerobic lagoons is that the 1.5 years that solids are held for provides sufficient time to build phase 2 treatment areas and finish the treatment process while all waste is contained
	Footprint area and access	3	- Area for treatment units is approximately 4,800m2 - Whole site area of 74,000m2 (at top of hill in camp 4 extension) - Road/vehicle access - Allowance in site area for phase 2 construction (solids treatment and gas handling)
	Speed of construction and setup	4	- Construction takes up to 6 months - Construction time is relatively long due to scale of site - The lagoons and polishing pond are large excavated structures lined with clay (local material) and plastic (imported)
	Resilience to disaster	3	- Excavated/earth structures so relatively resistant to earthquake and simple to repair (compared with concrete structures); however, the scale of the excavations makes construction access difficult - CXB site location is not prone to flooding
TREATMENT PROCESS	**Complexity of treatment process**	2	- Relatively simple, i.e. liquid treatment has 2 main processes with limited operator requirements - Biological process can be sensitive to incoming sludge characteristics. Oxfam is testing all incoming sludge from other NGOs
	Treatment effectiveness	2	- Site was commissioned in January 2019 so no quality data - Design is said to meet DoE and WHO standards, i.e. score 1, but in the absence of supporting data it was scored 2 - Retention time of the lagoons allows for settlement and some pathogen die-off, although the majority of the pathogen die-off will take place in phase 2 of the system.
	Pinch point		- TBC after sufficient time in operation
	Final discharge routes	1	- Liquid to surface water - Solids via planted drying bed (to be constructed under phase 2)
OPERATION AND MAINTENANCE	**O&M skills requirements**	3	- Three skilled staff needed to operate FSM site, including a mechanic - Daily checks needed, including checks on incoming sludge - The system runs using gravity (from inlet) so limited operator interaction required
COSTS	**CAPEX**	3	- $204,530 for phase 1 including design - $1,700 per m³ treated
	OPEX	1	- OPEX approximately $10,800 per year for FSM site labour or $0.25 per m3 treated - Desludging and transportation costs not included - Due to the scale of the plant, additional OPEX from transport will be incurred (not included in this assessment) - The system runs using gravity (from inlet) so limited OPEX for the plant itself
	WLC	5	- $322,760, assuming a plant life of 10 years and that 5% of materials need to be totally replaced once in that period (i.e. limited replacement of materials as the majority have a long life or were for initial excavation)

Most effective 1 ... 5 Least effective

Table 16:
Advantages and disadvantages of Anaerobic Lagoons

6.8 CENTRALISED BIOLOGICAL TREATMENT: **AEROBIC TREATMENT**

Aerobic Treatment

DESCRIPTION

An NGO has set up a pilot aeration FSM plant in Camp 18. The FSM plant has a capacity of 20m^3 per day but was operating at 10m^3 per day during the site visit. The FSM PFD and layout are shown in Figure 34 and Figure 35.

The main processing units are two Oxfam T45 tanks17 for aeration and settlement (in series). The site is a pilot to test if an aeration treatment system is feasible in a humanitarian response.

Sludge is manually delivered to the site in 50 litre drums and is emptied through a basic screen into the aeration tank. The aeration tank has a surface aerator and a mixer. The aerated conditions create the correct environment for the micro-organisms to treat the FS. The retention time in the aeration tank is approximately 20 hours, after which liquid is passed to the settlement tank. In the settlement tank flocs settle to the bottom and the liquid effluent is discharged from the top.

Some sludge from the bottom is returned to the aeration tank to keep the process active. The liquid effluent is passed through a glass bead filter to reduce any remaining solids and a chlorination tank before being discharged to surface water.

The surplus solids are extracted and treated at an adjacent lime treatment site, operated by the same NGO. It should be noted that aerobic treatment requires additional sludge handling and treatment (as with conventional wastewater treatment).

The site is powered for 24 hours a day by a generator, but the operating NGO is exploring if equipment can be powered by solar panels

(17) 45m^3 capacity, corrugated steel, circular tanks, See here for more details https://supplycentre.oxfam.org.uk/tank-kit-45-m-987-p.asp

PROCESS FLOW DIAGRAM AND SITE LAYOUT PLANS

Figure 34:
PFD - Aerobic Treatment

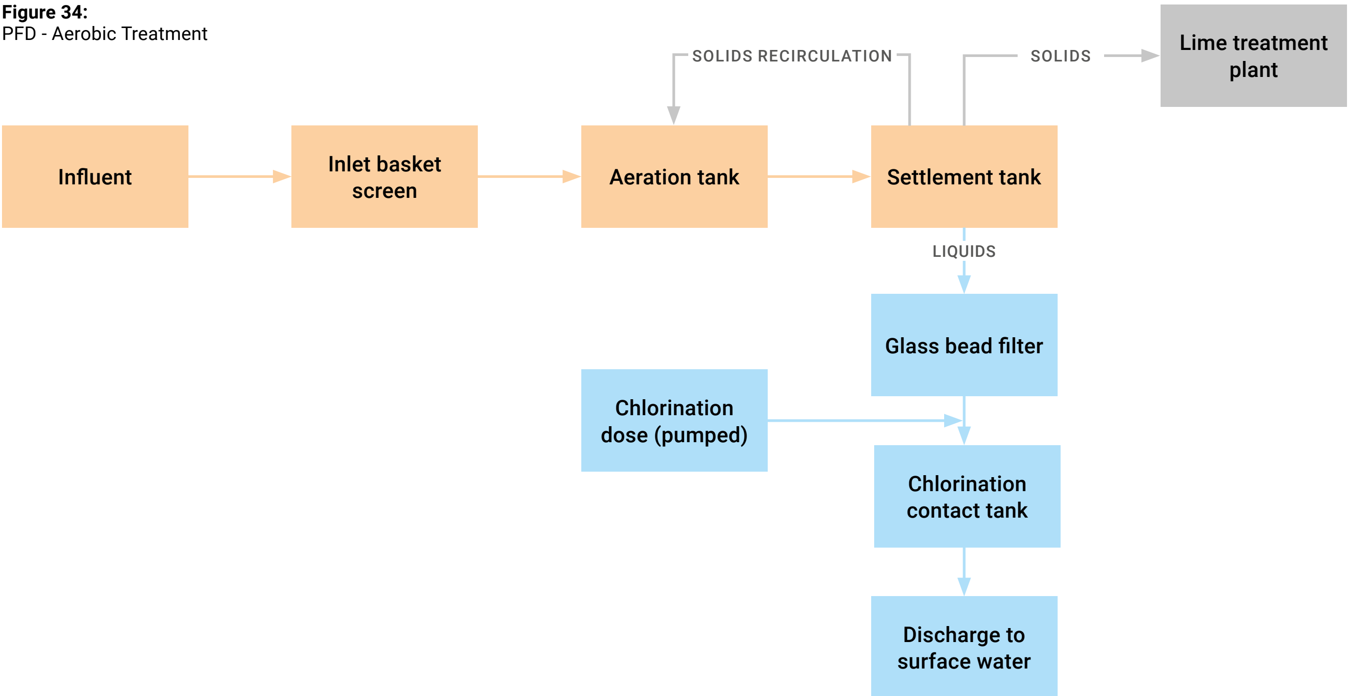
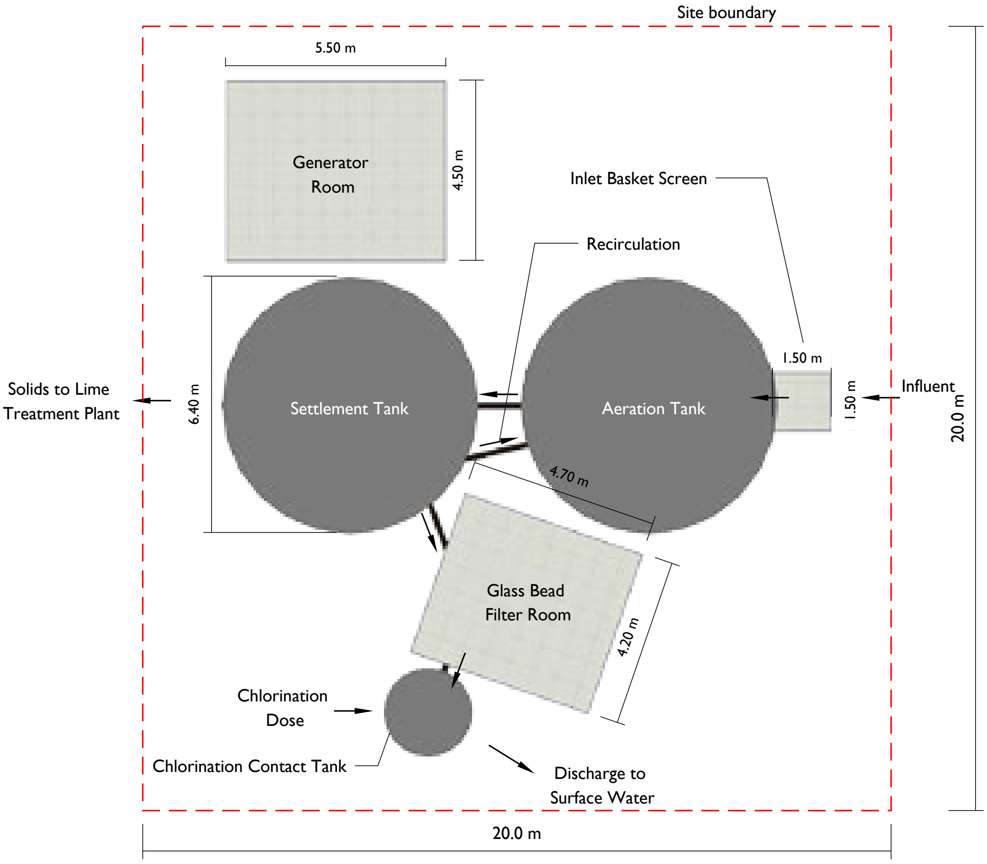


Figure 35:
Site layout plan - Aerobic Treatment



CENTRALISED BIOLOGICAL TREATMENT: **AEROBIC TREATMENT**

PHOTOS

Image 50:
Aeration tank

Image 51:
Settlement tank

Image 52:
Glass bead filter

Image 53:
Chlorine dosing

CENTRALISED BIOLOGICAL TREATMENT: **AEROBIC TREATMENT**

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		- 20m³ per day. Currently treating 10m³ per day
	Scale/scalability	2	- Additional tanks can be added in paralle
	Footprint area and access	1	- 265m³ for treatment units - Gravity flow from inlet to outlet - Compact equipment and layout. All treatment units are in prefabricated, so layout is flexible - Pedestrian access only
	Speed of construction and setup	2	- All treatment units are prefabricated tanks so quick to deploy (2 weeks to set up) - Commissioning takes time (approximately 30 days) and it also takes time to introduce sludge and get the process (micro-organisms) functioning
	Resilience to disaster	3	- Prefabricated tanks might be susceptible to earthquake but quick to repair - Top of tank could be raised if site is liable to flooding
TREATMENT PROCESS	**Complexity of treatment process**	4	- Relatively complex. Micro-organisms are sensitive to influent sludge characteristics, oxygen supply, retention time etc. - If a 'bad batch' of sludge is treated, it can take the process 30+ days to recover - Process needs monitoring and adjusting
	Treatment effectiveness	2	- Initial results show the plant is meeting DoE standards for nutrients and solids - Site is not meeting coliform standards; however, it is achieving helminth standards (for DoE or public health) - The liquid has a final disinfection step which ensures pathogen kill ahead of liquid discharge
	Pinch point		- Plant not operating at full scale, so pinch point TBC
	Final discharge routes	2	- Liquid portion is discharged to surface water. Disinfection is done prior to discharge - Excess solids are taken to a Lime treatment plant (i.e. they require further treatment to stabilise and achieve pathogen kill)
OPERATION AND MAINTENANCE	**O&M skills requirements**	5	- Skilled operator(s) required, although 1 or 2 can operate the site (not including desludging) - Daily tasks include backwashing of the glass bead filter, discharging effluent from the settlement tank to allow space for incoming flow, checks on chlorine dosing, generator checks, etc. - Annual maintenance of mechanical equipment required
COSTS	**CAPEX**	3	- CAPEX is approximately $27,300 or $1,365 per m³ treated based on plant achieving 20m³ per day capacity
	OPEX	2	- OPEX approximately $10,000 per year for labour, generator fuel and chlorine, plus an allowance for annual servicing. - $1.37 per m³ treated
	WLC	4	- $152,000 assuming a plant life of 10 years, and that 90% of materials need to be totally replaced once during that period (i.e. Oxfam tanks, pipework, etc.)

Most effective ◄ 1 ● ● ● 5 ► Least effective

Table 17:
Advantages and disadvantages of Aerobic Treatment

7 CONCLUSIONS

TECHNOLOGY

Designers and planners should consider site-specific factors in order to select the most appropriate FSM technology. The designers should weight the indicators according to what is most important for the site, e.g. footprint area, and use the information provided in sections 4 and 5 of this report (summary and comparison of technologies) and the multi-criteria analysis tool in Appendix F to guide them to the most appropriate technology. The disadvantages of the chosen FSM technology should then be reviewed to ensure any outstanding risks, e.g. liquid effluent quality, can be managed under the given site conditions.

In the immediate phase of an emergency, lime treatment is still considered the appropriate FSM technology choice due to its speed of setup, stability of the treatment process and effluent quality. However, due to the high OPEX of lime it is not appropriate to use it as a longer-term solution, i.e. after one or two years. Lime systems 1, 2 and 4 do not use concrete structures and can be constructed from simple excavated lined lagoons. They would therefore be appropriate to use in the short term as they are quick to construct, need limited amounts of materials and it is quick to return the site to its former condition.

For longer-term decentralised FSM technologies, the upflow filters score well against a number of the key indicators and are therefore considered the most effective 'all round' decentralised FSM technology. Space must be provided for adequate solids storage and liquid infiltration. Again, designers should consider the site-specific factors to determine if this technology is the most appropriate.

Of the centralised systems reviewed, the anaerobic lagoons are considered the more stable and simpler technology and therefore more appropriate in a refugee camp context (if space is available). It is considered that the OPEX figures for the plant viewed in CXB are relatively high and should reduce over time as less labour is required for everyday running.

COST

The FSM plants with the lowest WLC are the decentralised upflow filters and the ABR. The low OPEX of these systems was the greatest influence on WLC.

There was good use of local materials in CXB (e.g. bamboo); however the use of these less durable materials should be considered when assessing the WLC as bamboo, for example, would need to be replaced twice over 10 years adding CAPEX repeats to the WLC. Although the life of a plant is hard to establish, due to the transient nature of refugee camps, an estimate should be made to ensure a realistic WLC can be considered.

A 10-year life span was assumed for the WLC. If more details are known when planning a system, WLC should be calculated for the design life of the plant. A recommendation from this study is that a WLC tool/dashboard could be developed, allowing people to change life span and see how costs change.

FULL TREATMENT PROCESS

Adequate allowance (cost, area, operational skills, etc.) should be made for the full treatment process. This must include liquid and solids management and final disposal.

As mentioned, several plants visited (biogas, ABR, constructed wetlands and lime plant 2) did not include full liquids and solids treatment and disposal so additional costs will be incurred and area will be needed for these technologies.

Where infiltration is used for liquid disposal, infiltration tests should be used to determine the area required. Care must be taken to understand local groundwater conditions and avoid any contamination of groundwater resources. In CXB, 1.5m above groundwater level is taken as the minimum distance required to avoid contamination. However, this should be determined on a site-specific basis where infiltration is used.

For solids disposal, either adequate storage should be provided to allow storage for at least 24 months (or enough time to achieve pathogen die-off) or a final disposal location provided for burial.

General View CXB camp, surface water pond

APPENDICES

Appendix A1
List of Indicators

Below is the full list of indicators against which data was collected during site visits.

SITE SPECIFICS	Survey date/time
	Monitor/interviewee name
	Site/camp name
	Implementing/operating NGO
	Construction NGO
	Location (GPS coordinates: latitude, longitude and altitude)
	FSM identification number
	Phase of emergency
	PFD
	Area
	Topography
	Access and land tenure
	Typical site requirements (proximity to surface water and groundwater, utilities, etc.)
	Other
TECHNOLOGY	Type of treatment technology
	Functional?
	Life cycle/design life
	Scale (including typical PE to make it efficient)
	Population served
	Potential daily treatment volume/maximum daily treatment capacity
	Actual daily treatment volume
	Complexity (complicated technology/lots of equipment)
	Layout and footprint area
	Materials
	Speed of construction and setup
	H&S issues (with technology)
	Resilience to disaster
	Inputs

Table 18:
Full list of indicators assessed during study

(TREATMENT) PROCESS	Objective
	Treatment mechanism (mechanical, biological or chemical)
	Complexity of process (primary, secondary or tertiary)
	Robustness/stability
	Process pinch point
	Treatment effectiveness – compliance with WHO wastewater reuse standards, CXB FSM strategy and removal efficiency (BOD, COD and pathogens)
	Speed of commissioning
O&M	What needs doing
	Workforce requirements
	Skills requirements
	Maintenance frequency
	Materials and equipment
	Commissioning
	Monitoring
	Decommissioning
	H&S issues (with O&M)
	Other
COST	Capital expenditure (CAPEX)
	Operational expenditure (OPEX)
	Maintenance costs
	The whole life costs (WLC) of each technology
	Funding mechanism
	Other
ENVIRONMENTAL AND SOCIAL CONTEXT	Insights on understanding final discharge routes (environmental contamination)
	Nuisance (vectors)
	Social acceptance
	Legal context

Appendix B1
Technology comparison – Scored

		Decentralised biological and/or mechanical treatment				Decentralised biological treatment				Decentralised chemical treatment			
		Upflow filters	Upflow filters with pre-settlement (metal/ tarp tanks)	Upflow filter with pre-settlement (plastic tanks)	GeoTubes	Constructed wetlands 1	Constructed wetlands 2	Biogas plants	Septic/retention-tanks/ABR	Lime 1 Lagoon lime treatment with dewatering bed	Lime 2 Lagoon lime treatment with dewatering bed	Lime 3 Lagoon lime treatment with dewatering bed	Lime 4 In-barrel treatment with dewatering beds
Site Specifics	*Area*	3	3	5	2	4	2	1	1	4	1	3	3
	Topography	2	2	2	2	5	5	3	3	3	4	4	3
	Access and land tenure	2	2	2	2	2	2	3	3	3	3	3	2
Technology	*Scale (including typical PE to make it efficient)*	1	1	1	1	3	3	4	3	2	2	3	2
	Complexity (complicated technology/lots of equipment)	2	3	2	1	2	2	4	2	2	2	2	2
	Layout and footprint area	3	3	5	2	4	3	1	1	4	2	3	3
	Materials	2	2	3	3	2	2	3	3	1	1	3	1
	Speed of construction and setup	2	2	1	2	3	3	3	2	1	1	2	1
	H&S issues (with technology)	2	2	2	3	3	3	4	3	5	5	5	5
	Resilience to disaster	2	2	2	4	4	4	4	4	2	2	3	2
	Inputs	1	1	1	1	3	3	1	1	3	3	3	3

Table 19:
Full technology comparison scored

Lime 5 Three-tank lime system	Centralised biological treatment: Anaerobic lagoons	Centralised biological treatment: Aerobic treatment					SCORING RATIONALE
4	5	2	*1 is smallest area per m³ treated*	-	-	-	*5 is biggest area per m³ treated*
3	4	2	*1 is can be easily constructed on a variety of topographies (i.e. uneven site or flat site)*	-	-	-	*5 is needs flat site*
2	5	4	*1 is FSM plant can operate with pedestrian access only*	-	-	-	*5 is vehicle access is needed to operate FSM plant*
4	5	2	*1 is works at multiple scales. Quick and easy to scale up*	-	-	-	*5 is only works (well) at one scale. Difficult to scale up/down*
2	3	5	*1 is up to three main items of equipment (e.g. tank, basin, pump, filter) used, which are simple to maintain and operate*	*2 is up to three main items of equipment used, which are more complex to maintain and operate*	*3 is up to five main items of equipment used, which are simple to maintain and operate*	*4 is up to five main items of equipment used, which are more complex to maintain and operate*	*5 is five or more technology units used, which are complex to maintain and operate*
3	3	1	*1 is 0-14m²/m³ treated*	*2 is 15-29 m²/m³ treated*	*3 is 30-44 m²/m³ treated*	*4 is 45-60 m²/m³ treated*	*5 is more than 60 m²/m³ treated*
2	3	5	*1 is uses up to three local materials, commonly available and with local skills/knowledge. Easy to dismantle*	-	-	-	*5 is 5 or more imported materials,difficult to access*
1	4	2	*1 is less than 30 days*	*2 is 30-59 days*	*3 is 60-89 days*	*4 is 90-120 days*	*5 is more than 120 days*
4	2	3	*1 is low number of H&S risks noted (i.e. two) with low severity and low likelihood*	-	-	-	*5 is larger number of H&S risks noted (i.e. 3 or more) of high severity and high likelihood*
2	2	3	*1 is resilient to flooding and earthquake (integral to the technology/layout)*	-	-	-	*5 is low/no resistance to flooding or earthquake*
3	1	5	*1 is no external input required*	-	-	-	*5 is multiple external inputs required i.e. power, chemicals etc.*

Table continues on the next page

		Decentralised biological and/or mechanical treatment				Decentralised biological treatment				Decentralised chemical treatment			
		Upflow filters	Upflow filters with pre-settlement (metal/ tarp tanks)	Upflow filter with pre-settlement (plastic tanks)	GeoTubes	Constructed wetlands 1	Constructed wetlands 2	Biogas plants	Septic/retention-tanks/ABR	Lime 1 Lagoon lime treatment with dewatering bed	Lime 2 Lagoon lime treatment with dewatering bed	Lime 3 Lagoon lime treatment with dewatering bed	Lime 4 In-barrel treatment with dewatering beds
Treatment process	*Complexity*	2	2	2	2	3	3	3	2	3	3	3	3
	Robustness/ stability	3	3	3	2	3	3	3	3	2	2	2	2
	Treatment effectiveness	3	3	2	4	3	3	4	4	2	2	2	2
	Speed of commissioning	3	3	3	1	4	4	4	2	1	1	1	1
O&M	*Workforce*	2	2	2	3	2	2	3	1	3	3	3	3
	Skills requirements	2	2	2	2	2	2	3	2	4	4	4	4
	Frequency	2	2	2	3	2	2	3	1	4	4	3	4
	Materials and equipment	2	2	2	3	2	2	3	3	2	2	2	2
	Commissioning	3	3	3	2	3	3	3	2	2	2	1	2
	Decommissioning	2	2	1	1	4	4	4	5	3	3	4	3
	H&S issues (with O&M)	2	2	1	3	2	3	3	3	5	5	5	5

	Centralised biological treatment		SCORING RATIONALE				
Lime 5 Three-tank lime system	Anaerobic lagoons	Aerobic treatment					
3	2	4	*1 is up to 3 simple processes using the same removal mechanism, and simple to commission and keep working*	*2 is up to 5 simple processes using the same removal mechanism, and simple to commission and keep working*	*3 is up to 5 simple process with a mix of removal mechanisms, and easy to commission and keep working. Or includes chemical dosing i.e. lime*	*4 is up to 5 more complicated process with a mix of removal mechanisms, and more complicated to commission and keep working*	*5 is more than 5 complex processes with a mix of removal mechanisms, and complicated to commission and keep working*
2	3	4	*1 is whole process is not sensitive to changes in influent, inputs (chemicals, aeration etc.) or changes in environmental conditions*	*2 is that 1 part of process is sensitive to changes in influent, inputs (chemicals, aeration etc.) or environmental conditions, but this will not have a large impact on the effluent quality*	*3 is that 1 part of process is sensitive to changes in influent, inputs (chemicals, aeration etc.) or environmental conditions, and this will have an impact on the effluent quality*	*4 is multiple processes that are sensitive to changes in influent, inputs (chemicals, aeration etc.) or environmental conditions which will reduce the final effluent quality*	*5 is the majority of the processes are highly sensitive to changes in influent, inputs (chemicals, aeration etc.) or environmental conditions which will reduce the final effluent quality*
2	2	2	*1 is final liquid and solids meets all DoE, WHO standards and classified as 'good' under CXB FSM strategy. Weighting given to coliform removal.*	*2 meets public health coliform standards and classified as 'good' under CXB FSM strategy i.e. liquid & solids disposal avoids contact.*	*3 is site classed as 'acceptable' under CXB FSM strategy but does not meet DoE or WHO coliform standards for liquid effluent*	*4 is site classed as 'unacceptable' under CXB FSM strategy, and does not meet DoE or WHO E.coli standards for liquid effluent, BUT a high %reduction in coliform level is achieved*	*5 is site classed as 'unacceptable' under CXB FSM strategy and does not meet DoE or WHO coliform standards for liquid effluent. Low coliform removal.*
1	2	3	*1 is fast i.e. less than 14 days*	-	-	-	*5 is slow i.e. biological process that needs months to reach full treatment efficiency*
1	3	5	**1 is a low number (i.e. less than 3) of staff needed for daily operation of the FSM plant**	-	-	-	**5 is a high number (i.e. more than 8) of staff needed for daily operation of the FSM plant**
3	3	5	*1 is no skilled labour required*	*2 is one skilled labourer needed*	*3 is three skilled labourers needed*	*4 is specialist skills needed for the majority of the daily operation. Includes chemical / lime dosing.*	*5 is highly skilled labour needed throughout operation*
2	4	4	*1 is low frequency of O&M needed (i.e. once per week)*	-	-	-	*5 is high level of O&M needed, i.e. daily*
2	2	5	*1 is not much equipment or materials needed for O&M. Or commonly available equipment/ materials only.*	-	-	-	*5 is specialist equipment/ materials needed for O&M*
1	3	5	*1 is fast and simple commissioning*	-	-	-	*5 is complicated commissioning with multiple processes*
4	5	2	*1 is fast and easy to decommission and remove equipment i.e. clear the site and reuse equipment elsewhere*	-	-	-	*5 is 'permanent structures' difficult to remove and residual waste to dispose of offsite e.g. solids, contaminated media etc.*
4	3	3	*1 is low number of H&S risks in O&M operations*	-	-	-	*5 is high number of H&S risks in O&M operations*

Table continues on the next page

		Decentralised biological and/or mechanical treatment				Decentralised biological treatment				Decentralised chemical treatment				
		Upflow filters	Upflow filters with pre-settlement (metal/ tarp tanks)	Upflow filter with pre-settlement (plastic tanks)	GeoTubes	Constructed wetlands 1	Constructed wetlands 2	Biogas plants	Septic/retention-tanks/ABR	Lime 1 Lagoon lime treatment with dewatering bed	Lime 2 Lagoon lime treatment with dewatering bed	Lime 3 Lagoon lime treatment with dewatering bed	Lime 4 In-barrel treatment with dewatering beds	Lime 5
Cost	*CAPEX*	5	5	4	1	5	3	2	1	2	2	3	3	
	OPEX	2	2	2	2	2	1	1	1	4	3	5	4	
	WLC of each technology	2	2	2	3	2	2	1	2	5	5	5	5	
Environmental and social context	*Insights on understanding final discharge routes (environmental contamination)*	2	2	1	5	3	4	4	4	2	4	3	2	
	Nuisance (vectors)	4	4	2	4	2	3	2	2	2	1	1	1	
	Social acceptance	3	3	2	4	2	2	2	1	3	2	2	3	

	Centralised biological treatment						
Lime 5 Three-tank lime system	Anaerobic lagoons	Aerobic treatment	SCORING RATIONALE				
3	3	3	*1 is $0 to $500*	*2 is $501 to $1500*	*3 is $1501 to $3000*	*4 is $3001 to $5000*	*5 is $5001 +*
4	1	2	*1 is up to $0.5 per m³ treated*	*2 is $0.5 to $5*	*3 is $5 to $10*	*4 is $10 to $15*	*5 is more than $15*
4	5	4	*1 is less than $20,000*	*2 is $20,001 to $50,000*	*3 is $50,001 to $100,000*	*4 is $100,001 to $200,000*	*5 is more than $200,000*
2	1	2	*1 is 'good' discharge routes, i.e. in line with CXB FSM strategy e.g. infiltration, burial, incineration. A clearly planned disposal route and adequate space included.*	-	-	-	*5 is poor allowance and difficult management of final products/wastes*
1	2	1	*1 is no obvious nuisance/ vectors that are within FSM plant control*	-	-	-	*5 is nuisance/vectors present or potentially so*
1	3	3	*1 is a contained plant with limited impact on social norms*	-	-	-	*5 is obvious public nuisance and complaints*

Appendix B2
Technology Comparison - Full Information

This spreadsheet has been issued separately but can also be accessed here:
https://arup.sharefile.com/d-s6f2d00b5a194ad3a

An online multicriteria tool, developed as part of this project, can be accessed here:
https://arup.sharefile.com/d-secb5d47e7254b18b

Appendix C1
Influent Characteristics

Parameter	Units	Typical (from literature) Pit latrine/public toilet sludge	CXB Pit Latrines (average based on UPM data[17])	Typical (from literature) septic tank	septic ta
pH		6.5 – 9.5	7	6.5 – 12.5	
BOD_5	mg/l	150 – 300	201	840 – 2,600	
COD	mg/l	20-50,000	527	<10,000	1
COD:BOD	ratio	2:1 to 5:1	3:1	5:1 to 10:1	
Total solids (TS)	mg/l	30,000 – 50,000	15,490	12,000 – 35,000	5
TS	%	≥3.5	2	<3	
Total dissolved solids (TDS)	mg/l	200 - 5000	3,758		6
Total volatile solids (TVS)	% of TS	65 – 68%	68	45 - 75	
Suspended solids (SS)	mg/l	>30,000	353	>7,000	
NH_4-N	mg/l	2,000 – 4,000	695	150 - 1000	
E.coli	cfu/ml	1 x 105	6.25E+05	1 x 105	
Nematode/helminth eggs	No./l	20 to 60,000	967	4,000	N
Volume	l/h/d	0.15-0.2 l/h/d	0.4	2	

(17) UPM excel sheet titled 'WP3 FSTP (23.01.19)' received by email.

Table 20:
FS Influent Characteristics

CXB nk (average)	CXB influent (combined) (average)	
7	9	*In range*
385	1,712	*In range; low for septic tank (but CXB are using holding tanks not sceptic tanks)*
,183	6,414	*COD low (note that IFRC found it to be high from tests at the aeration site)*
3:1	3:1	*In range; low for septic tank (but CXB are using holding tanks not sceptic tanks)*
,014	15,292	*Low but ok on average; collection tanks may get some settlement.*
1	1.46	*In range*
,481	4,594	*In range*
50	57	*In range*
	353	*Low*
710	881	*In range (possibly low)*
194	7.43E+05	*High (ignore septic tank result)*
o data	967	*Low*
0.4	0.4	*High but limited data. Include wastewater from washing in the latrine?*

Appendix C2
Effluent Quality

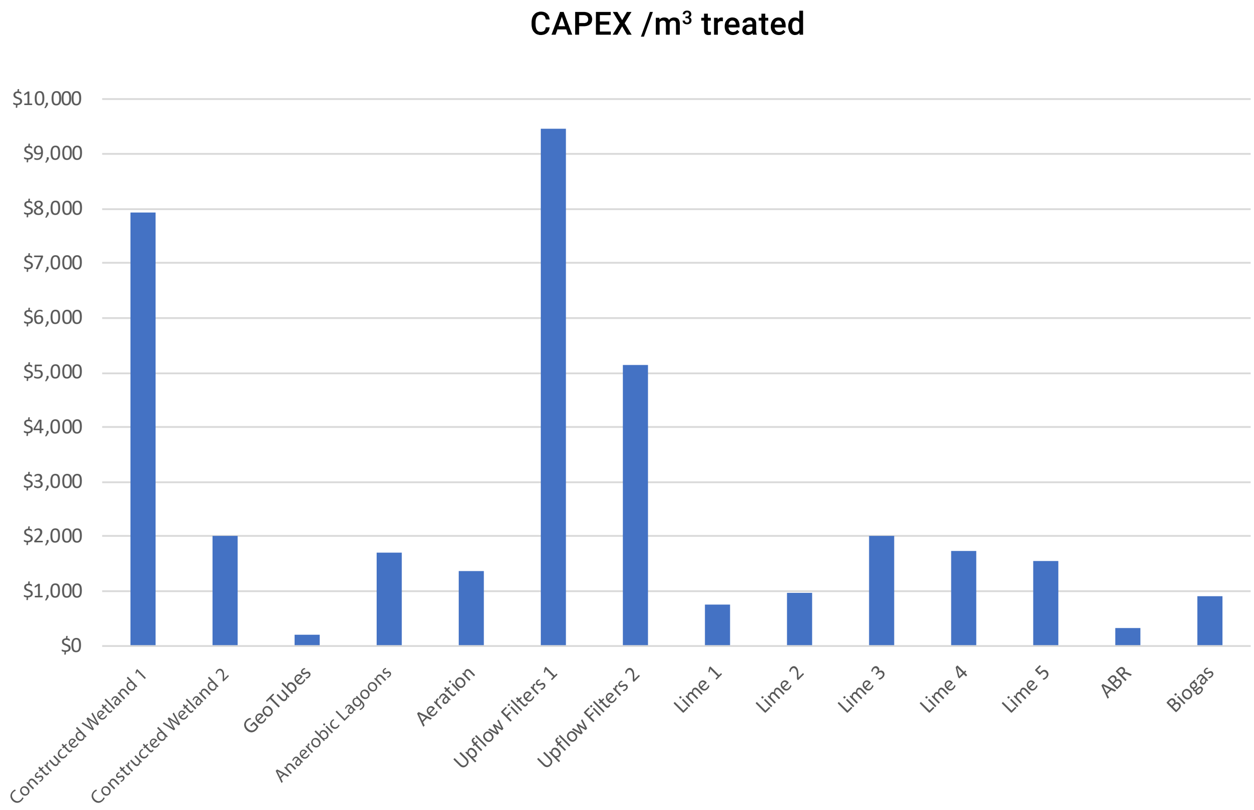
In some cases, the UPM testing performed was not at the same sites as visited by Arup but represents the same technology.

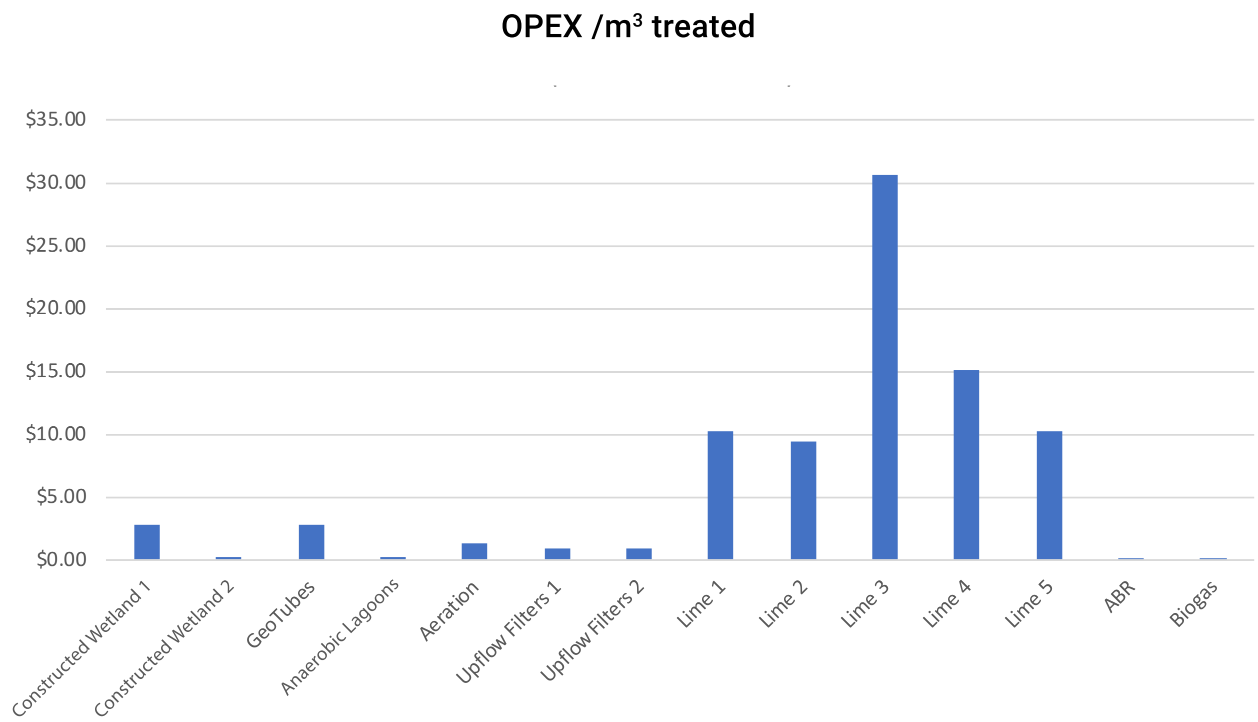
Parameter	Units	Bangladesh DoE guidelines (pending 2019)	Public health Standard (based on WHO agricultural reuse standards)	#1 Biogas plant with lime treatment [FS ID: BGP C-18]	#2 ABR with drying and filter bed [FS ID: STF E3]	#3 ABR with drying and filter bed [FS ID: ACF - EE06]	#5 ABR with horizontal fil and discharg into channel
Does liquid meet DoE standards?							
pH		9		YES	YES	NO	YES
BOD5	mg/l	30		NO	NO	NO	NO
Total Nitrogen	mg/l	15		YES	NO	YES	NO
Nitrate	mg/l	250		YES	YES	YES	YES
Phosphate	mg/l	35		YES	YES	YES	YES
Suspended solids (SS)	mg/l	100		YES	YES	YES	YES
Temperature	Celsius	30		YES	YES	YES	YES
Coliform	CFU/100 ml	1000		YES	YES	NO	YES
Oil and grease	mg/l	10		0	0	0	0
COD	mg/l	200		NO	NO	NO	NO
Does liquid meet protection of public health (WHO) standard?							
Coliform	CFU/100 ml			YES	YES	NO	NO
Helminth (Ascaris lumbricoidis)	no./l			NO	NO	NO	NO
Helminth eggs in effluent	No./l		1	10,000	0	10,000	200
Coliforms in effluent	CFU/100 ml		1000	300	0	25,000	300,000
Coliform reduction	CFU/100 ml			2,799,700	3,000	45,000	-1,700,00
Do solids meet protection of public health (WHO) standard?							
Coliform	CFU/100 ml			NO	YES	NO	NO
Helminth (Ascaris lumbricoidis)	No./l			NO	NO	NO	NO

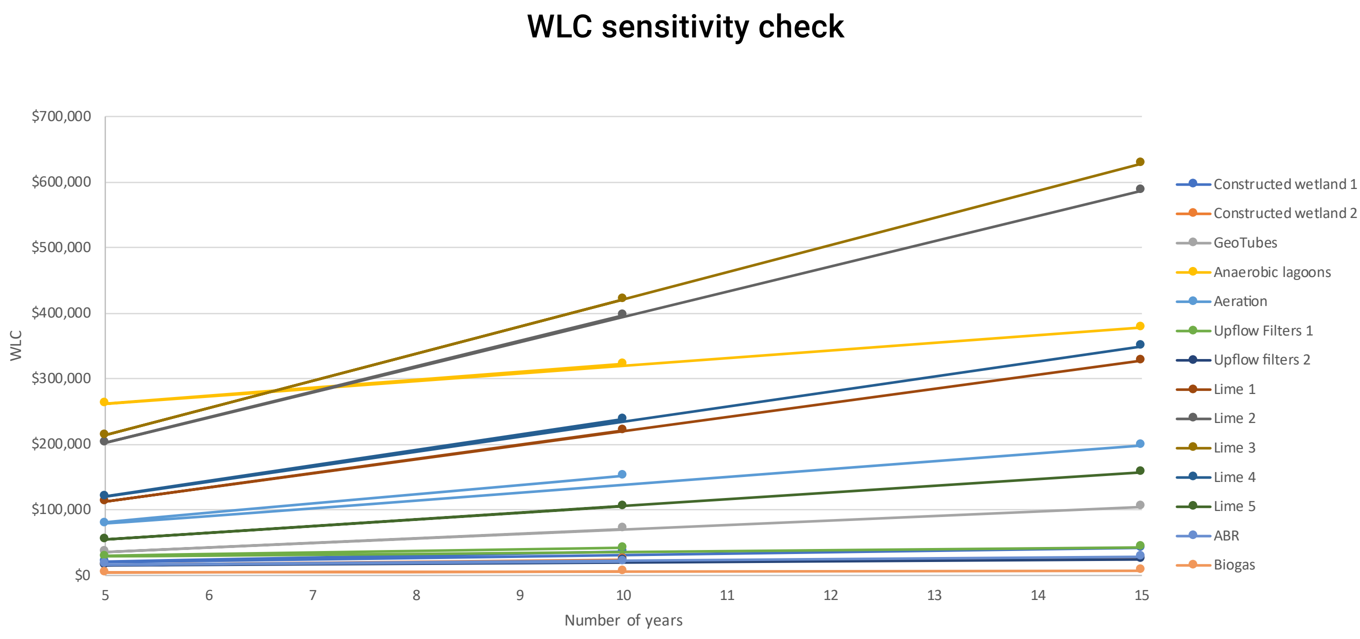
Table 21:
FS Effluent Characteristics

lter ge	#6 GeoTube with lime treatment and infiltration [FS ID: Camp 21 - SI]	#7 Upflow filter Plant 1 [FS ID: Camp 7 - Practical Action - Plant 3]	#8 Lime 1 [FS ID: Oxfam FSM 1]	#10 Lime 4 [FS ID: IFRC LTP]	#11 Aerobic treatment [FS ID: IFRC ATP]
	YES	YES	NO	NO	YES
	YES	NO	NO	NO	0
	NO	NO	NO	NO	0
	YES	YES	YES	YES	YES
	YES	YES	NO	NO	YES
	YES	YES	NO	YES	YES
	YES	YES	YES	YES	YES
	NO	NO	YES	YES	NO
	0	0	0	0	0
	YES	NO	NO	NO	NO
	NO	NO	YES	YES	NO
	YES	NO	NO	YES	YES
	0	100	100	0	0.6
	4,500,000	13,000	0	0	150,000
0	-2,500,000	1,960,000	180,000	1,500,000	850,000
	NO	NO	YES	YES	YES
	NO	NO	NO	YES	NO

Appendix D
WLC, CAPEX and OPEX Details



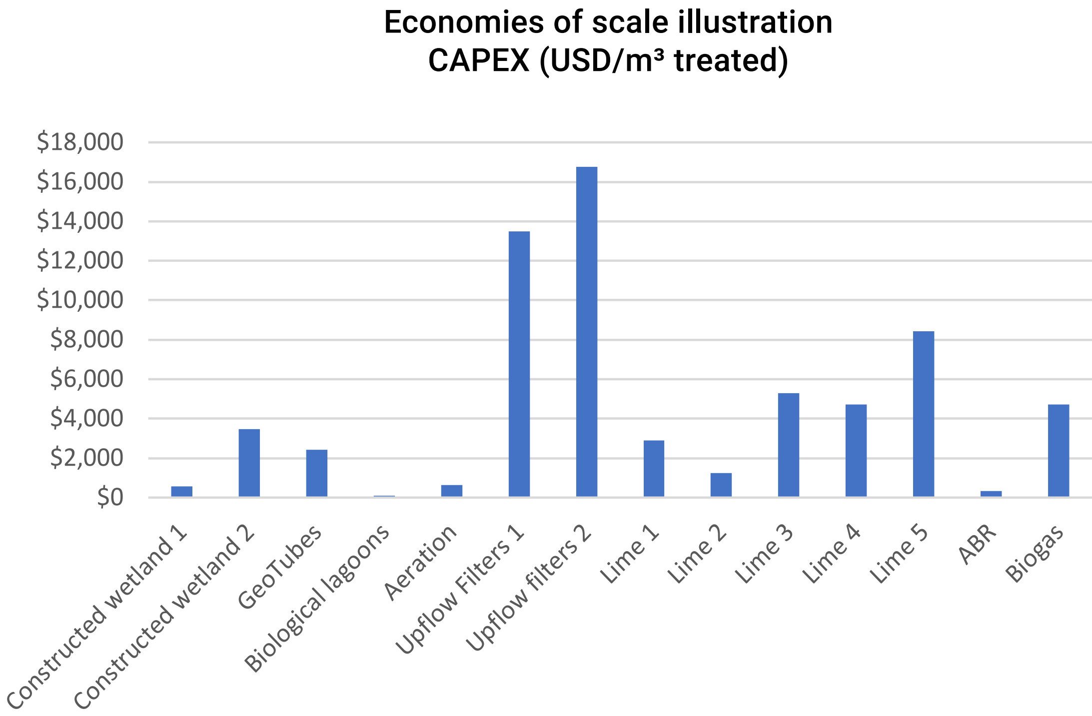

OPEX /m³ treated
$35.00
$30.00
$25.00
$20.00
$15.00
$10.00
$5.00
$0.00
Constructed Wetland 1
Constructed Wetland 2
GeoTubes
Anaerobic Lagoons
Aeration
Upflow Filters 1
Upflow Filters 2
Lime 1
Lime 2
Lime 3
Lime 4
Lime 5
ABR
Biogas

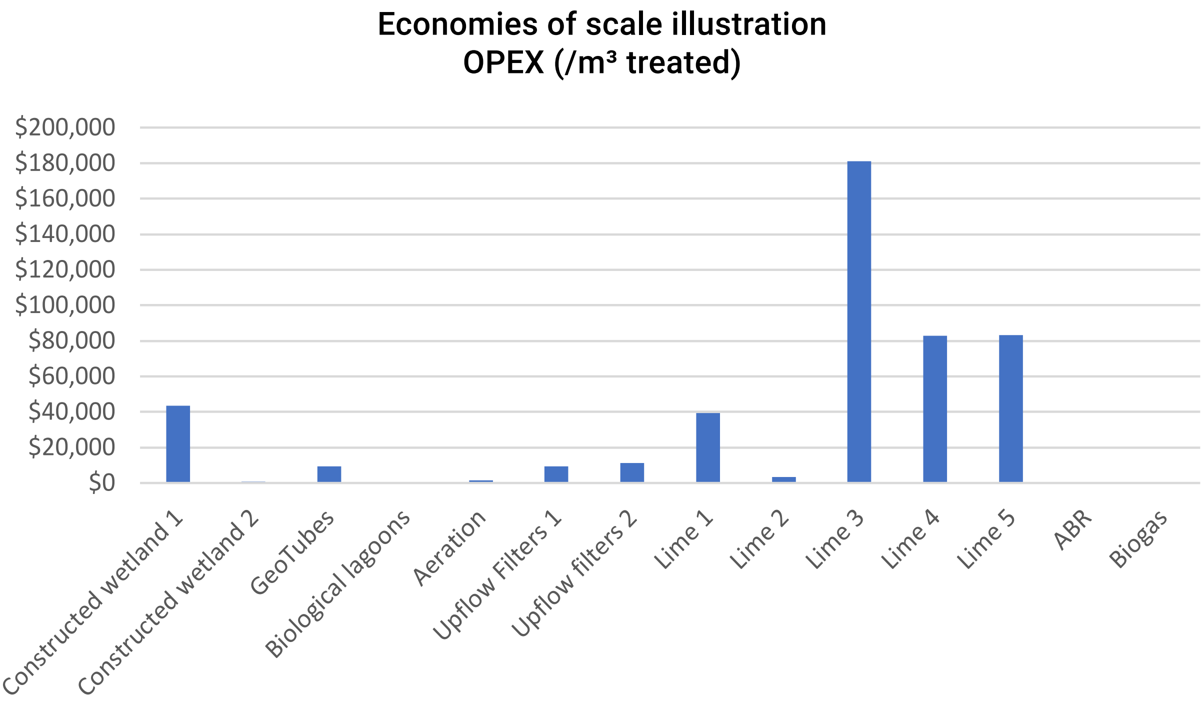

WLC sensitivity check
$700,000
$600,000
$500,000
$400,000
$300,000
$200,000
$100,000
$0
WLC
5
6
7
8
9
10
11
12
13
14
15
Number of years
Constructed wetland 1
Constructed wetland 2
GeoTubes
Anaerobic lagoons
Aeration
Upflow Filters 1
Upflow filters 2
Lime 1
Lime 2
Lime 3
Lime 4
Lime 5
ABR
Biogas

Appendix E
Centralised / Decentralised - Economies of Scale

One anaerobic lagoon with a capacity of 60m^3 per day versus multiple decentralised plants

Site	Treatment capacity (m^3/d)	Number of plants required for a capacity of 60m^3/d	CAPEX ($)	CAPEX ($/m^3 treated)	OPEX ($/yr)	OPEX ($/m^3 treated)	WLC ($)
Constructed wetland 1	1.43	42.00	$33,480	$558	$62,093	$43,465	$684,540
Constructed wetland 2	5.00	12.00	$17,280	$3,456	$4,493	$899	$79,488
GeoTubes	6.50	9.23	$15,785	$2,428	$61,676	$9,489	$664,117
Biological lagoons	120.00	0.50	$11,070	$92	$5,400	$45	$65,624
Aeration	20.00	3.00	$12,420	$621	$30,043	$1,502	$324,025
Upflow Filters 1	2.00	30.00	$27,000	$13,500	$19,008	$9,504	$241,380
Upflow filters 2	1.75	34.29	$29,314	$16,751	$19,749	$11,285	$250,251
Lime 1	5.71	10.50	$16,470	$2,882	$224,154	$39,227	$2,271,186
Lime 2	11.00	5.45	$13,745	$1,250	$37,973	$3,452	$401,724
Lime 3	3.70	16.22	$19,557	$5,286	$669,250	$180,878	$6,714,010
Lime 4	4.00	15.00	$18,900	$4,725	$331,776	$82,944	$3,365,010
Lime 5	2.70	22.22	$22,800	$8,444	$224,320	$83,081	$2,268,280
ABR	35.00	1.71	$11,726	$335	$1,370	$39	$26,599
Biogas	4.00	15.00	$18,900	$4,725	$1,255	$314	$39,005


Economies of scale illustration
CAPEX (USD/m³ treated)
$18,000
$16,000
$14,000
$12,000
$10,000
$8,000
$6,000
$4,000
$2,000
$0
Constructed wetland 1
Constructed wetland 2
GeoTubes
Biological lagoons
Aeration
Upflow Filters 1
Upflow filters 2
Lime 1
Lime 2
Lime 3
Lime 4
Lime 5
ABR
Biogas


Economies of scale illustration
OPEX (/m³ treated)
$200,000
$180,000
$160,000
$140,000
$120,000
$100,000
$80,000
$60,000
$40,000
$20,000
$0
Constructed wetland 1
Constructed wetland 2
GeoTubes
Biological lagoons
Aeration
Upflow Filters 1
Upflow filters 2
Lime 1
Lime 2
Lime 3
Lime 4
Lime 5
ABR
Biogas

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