Faecal Sludge Management for Disaster Relief

Technology Comparison Study

Contents

EXECUTIVE SUMMARY

Arup have conducted this technical comparison study on Faecal Sludge Management (FSM) for disaster relief on behalf of Oxfam. The findings are based on evidence gathered in the Rohingya refugee camps close to Cox's Bazar (CXB), Bangladesh.

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. **Aeration Plant**
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 1 ("good") to 5 ("bad") has been given to each technology for each indicator. The total scores give an indication of an overall "good" choice. This has shown that Upflow Filters (with presettlement) are the best for decentralised FSM and the Aeration Plant best for centralised FSM. Although these technologies have the lowest/best scoring they still have limitations and selection should be informed by site conditions.

Footprint area and costs were two indicators of interest in this study. The footprint area comparison showed that, the technologies that provide full FS treatment and have the lowest footprint area, are the lime treatment sites.

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 \$), assuming a 10-year design life. The lowest WLC FSM plant 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 a relatively high CAPEX due to the size of the infrastructure, so a higher WLC.

Another key finding from CXB was that adequate allowance (cost, area, operational skills etc) should be made for the full treatment train. This must include liquid and solids management and final disposal.

General view, camp 6

1 INTRODUCTION

Arup have conducted this technical comparison study of Faecal Sludge Management (FSM) techniques for disaster relief, on behalf of Oxfam UK (Oxfam). The aim of the study is to draw conclusions on best practice 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
- Aeration Plant
- 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/ or 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
- Aeration Plant

2 METHODOLOGY

As noted above, eight technologies were reviewed as part of this study[1]. All sites had a minimum capacity of 5m³/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 consider when planning a FSM plant. The indicators are also in line with those used by other consultancies/NGOs during assessments conducted of CXB FSM sites[2]. This ensures that the data collected by Arup is comparable. A background review was conducted to understand typical ranges for each indicator for each technology[3]. This is presented in a separate background study report.

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

- **Capital and operational costs (CAPEX and OPEX);**
- **Area requirement and layout;**
- **Speed of construction and commissioning;**
- **Expertise required for set up and operate;**
- **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 technologies initially identified in the Oxfam scope document. It was agreed with Oxfam to focus on sites with a minimum plant capacity of 5m³/day which dictated the technologies reviewed.
(2) i.e. the Octopus Case Studies and NGO factsheets. See https://octopus.solidarites.org/.
(3) A majority of the FSM examples reviewed (outside of the Rohingya refugee camps in CXB) are not for disaster relief (due to lack of reliable published data), however the background study has focused on a development context. Effort has been made to use unbiased and accredited sources of information, however, due to the limited practical experience of some of the technologies implement this has not always be 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[4], including: pathogen removal mechanism and efficiency; and stability to changes in climate or influent characteristics.
- **Operation and maintenance**
  Including; tasks, workforces, skills required and health and safety
- **Cost**
  Example indicators; CAPEX and OPEX
- **Environmental and social context**
  Including; understanding final discharge routes, nuisance and social acceptance

Site data was collected from participating NGOs, site visits and site measurements, as well as background information provided by Oxfam, United Nations High Commission for Refugees (UNHCR) and Octopus[5].

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

A rating system of 1 to 5, has been applied for each indicator for each technology. This gives an overview of the advantages and disadvantages of each and informs the selection of the most appropriate technology in a future context.

(4) Several technologies may employ the same treatment process e.g. anaerobic digestion.
(5) Octopus is an online collaboration programme for FSM, operated by Solidarity 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 from 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 draw replicable conclusions from the technologies in operation in CXB.

COST

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

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

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

Whole Life Costs (WLC) has been calculated to give the overall costs to operate the FSM plant for 10 years. The WLC is 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.

SLUDGE CHARACTERISTICS

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 visited by Arup but represents the same technology. Additional data from NGOs monitoring has also been considered[6].

As noted above the incoming sludge characteristic have a large influence on the technology choice, treatment efficiency and the costs. A comparison of CXB sludge characteristics (from UPM study) Vs typical parameters (from 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)[7], giving some confidence that the findings from CXB can be transferred to another geographical context. The site data did show that the FS has relatively low solids and high volumes, with low level of nutrients, likely due to the low levels of cleaning products entering the wastewater.

EFFLUENT STANDARDS

Effluent quality from sites (from UPM data) was compared against the Bangladesh Department for Environment (DoE) standards for discharge to inland watercourse and the World Health Organisation (WHO) 2006 'Guidelines for the safe use of wastewater'[8]. 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 pathogen exposure to workers throughout the treatment process and of the public from the end products. Site (and country) specific effluent quality should be considered when selecting a FSM technology.

CENTRALISED AND DECENTRALISED

In this study 'centralised' is taken to mean a large FSM plant i.e. treatment capacity over 20m^3/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/d. Household scale technologies have not been considered as part of this study.

Economies of scale can be achieved with centralised plant Vs decentralised e.g. one Anaerobic Lagoon FSM plant Vs 10No. Lime plants. An illustration of the costs can be found in Appendix E.

(6) Effluent sample data was provided by Solidarity International and IFRC for the GeoTubes and Aeration plant respectively.
(7) 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.
(8) 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 1 ("good" shown in green) to 5 ("bad" shown in red) has been applied for each indicator with the scoring rational 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 totalised giving an indication of an overall "good" choice. This has shown that Upflow Filters (with presettlement) are the best for decentralised FSM and the Aeration Plant best for centralised FSM. Although these technologies give the lowest/best scoring 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 given site conditions.

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 m³ treated and presented in US Dollars ($).[9]

The footprint area comparison (Figure 1) showed that the ABR, aeration and biogas systems had the lowest footprint area per m³ 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[10] sites.

Area required by each technology (m²/m³ treated)

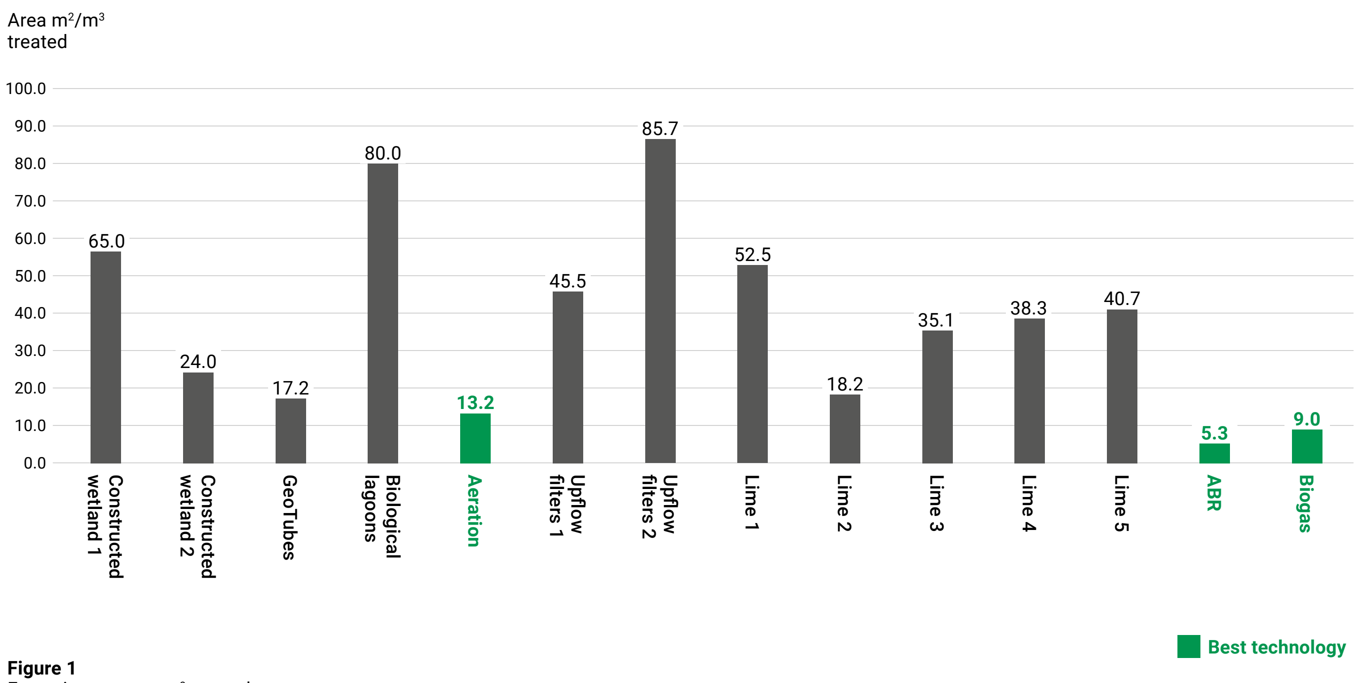


Figure 1
Footprint area per m³ treated

The costs comparison includes CAPEX ($ per m³ treated), OPEX ($ per m³ treated) and the WLC ($). The WLC is 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 the ABR and the biogas plants have the lowest WLC. This is due to the low OPEX of these systems and longevity of materials used, so low number of CAPEX repeats. Lime had a relatively high WLC due to the high OPEX (cost of hydrated lime). See cost comparison in Figure 1, 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 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. 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.

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

Whole Life Costs for 10 years

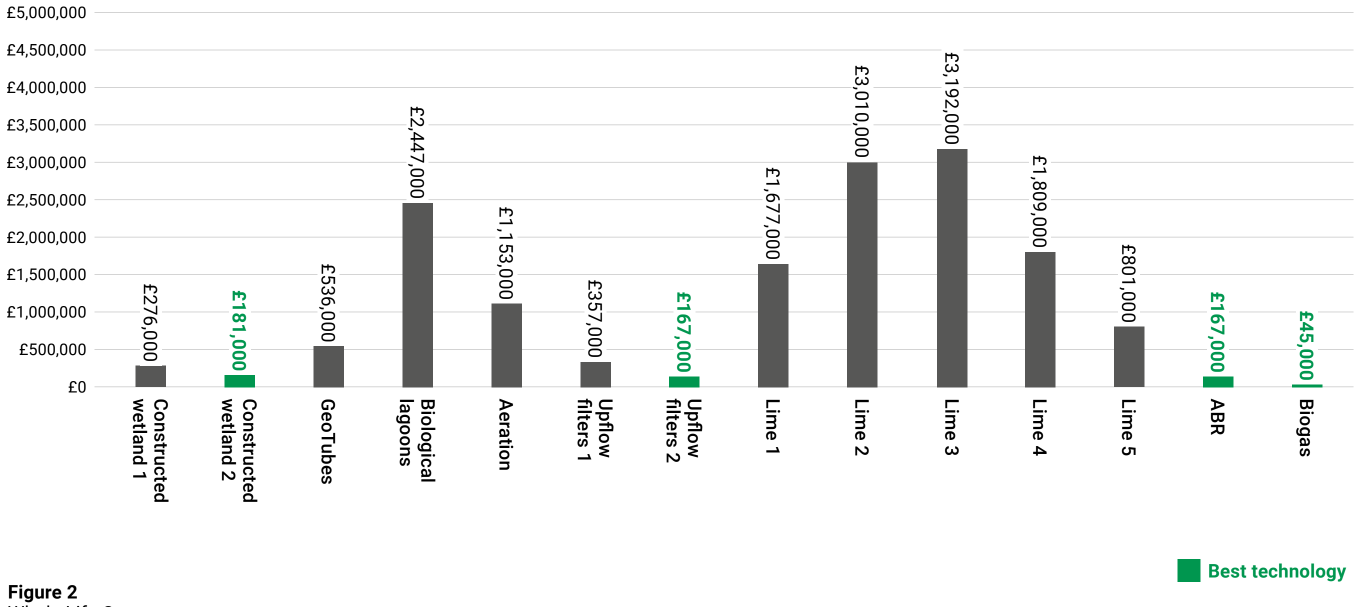
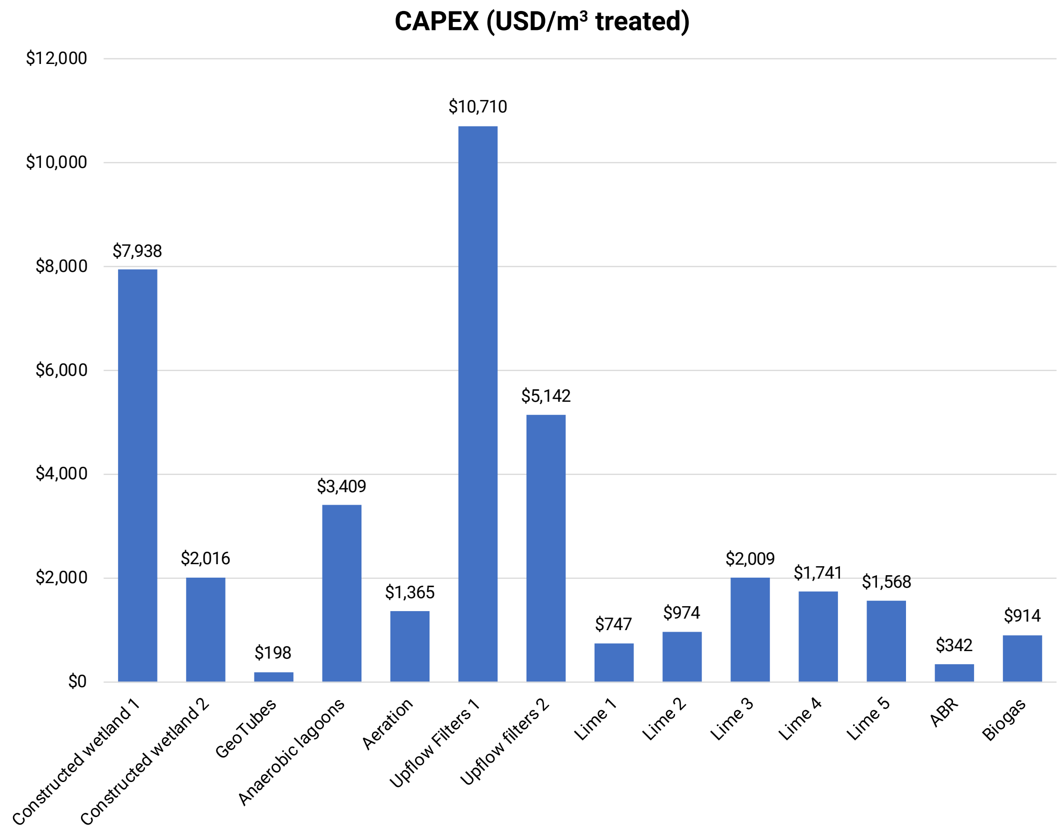
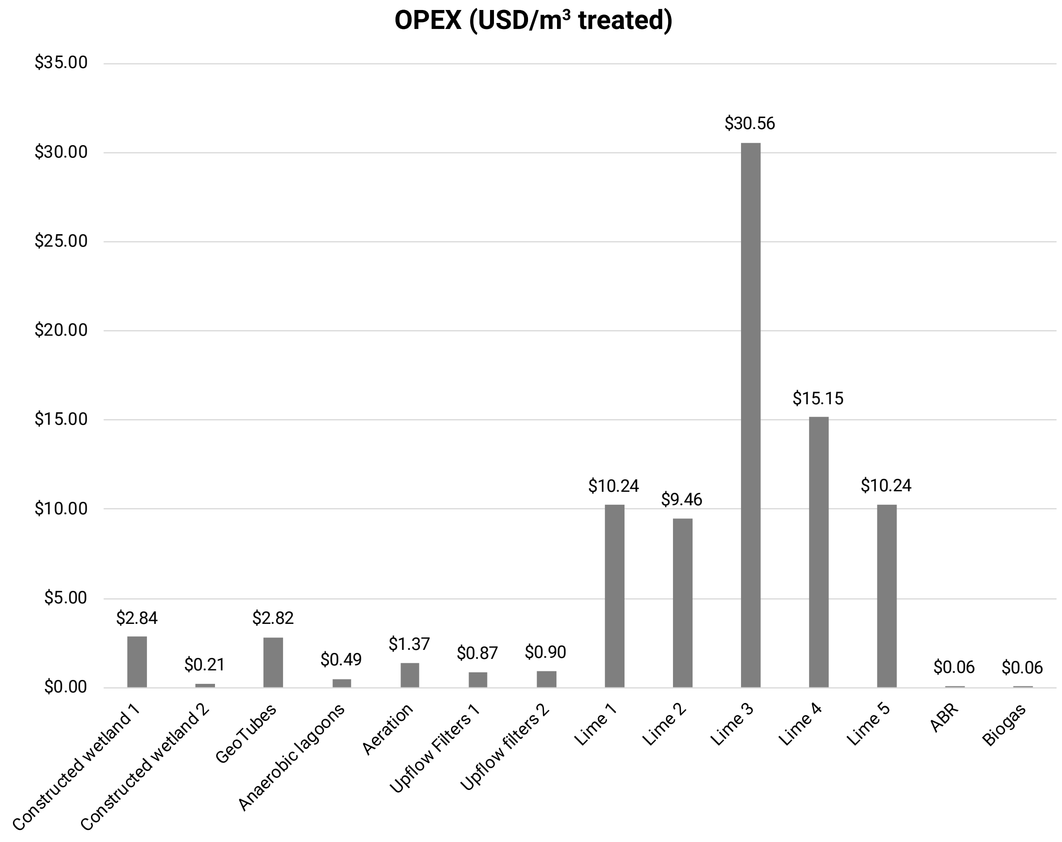
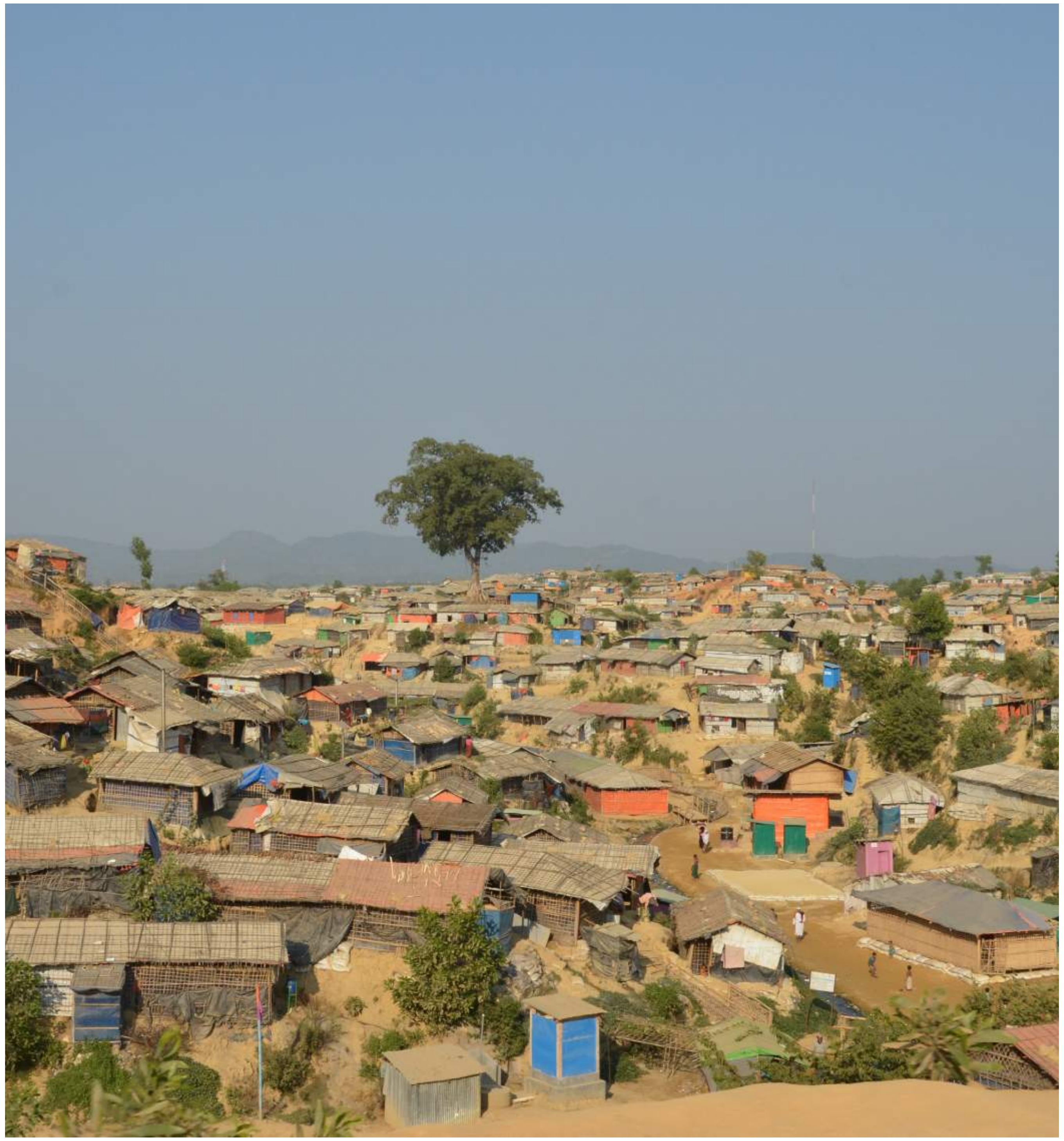


Figure 2
Whole Life Cost

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					Centralised biological treatment		SCORING RATIONAL	
		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 3 tank lime system	Anaerobic Lagoons	Aeration Plant	1	5
Technology	*Scale*	1	1	1	1	3	3	4	4	2	2	3	2	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*
	Complexity of technology & equipment	3	3	2	1	2	2	4	2	2	2	2	2	2	3	5	*1 is simple technology, easy to operate with limited equipment needed*	*5 complex technology*
	Layout and footprint area	2	2	1	2	4	4	3	4	3	3	3	2	3	4	2	*1 is laid out for easy operation, flexible layout (to suit site conditions) and low footprint area (per m³ treated)*	*5 is fixed layout and low footprint area (per m³ treated)*
	Speed of construction & set up	1	1	1	2	3	3	4	3	2	2	4	2	3	5	2	*1 is fast to construct and set up*	*5 is slow to construct and set up*
	Resilience to disaster	1	1	2	5	3	3	4	4	2	2	3	2	2	3	3	*1 is resilient to flooding and earthquake (integral to the technology/layout)*	*5 is low/no resistance to flooding or earthquake*
(Treatment) Process	*Complexity of process (primary, secondary, tertiary)*	1	3	3	1	3	3	4	3	2	2	2	2	2	3	5	*1 is simple with low number of treatment processes*	*5 is complex with multiple processes including biological*
	Robustness/ stability	3	3	3	2	3	3	4	2	1	1	1	1	1	4	5	*1 is robust, resistant to changes in influent, operation and climate*	*5 is sensitive to changes in influent, operation and climate*
	Treatment effectiveness	3	3	2	5	2	3	3	3	3	4	3	2	3	2	1	*1 is "good" under CXB FSM strategy and meets DoE and WHO standards*	*5 is "unacceptable" under CXB FSM Strategy and does not meet DoE or WHO standards*
Operation and maintenance	*Skills requirements*	2	2	2	3	1	1	3	1	3	3	3	3	2	3	5	*1 is a low level of skills (i.e. general sanitation skills) required to operate FSM plant*	*5 is a highly skilled operation/ technology specific i.e. above general skills of trades people*
Cost	*Capital expenditure costs (CAPEX $/m³ treated)*	5	5	4	1	4	3	2	1	2	2	3	3	3	4	2	*1 is lowest CAPEX ($/m³ treated)*	*5 is highest CAPEX ($/m³ treated)*
	Operational expenditure (OPEX $/m³ treated)	1	1	1	3	3	1	1	1	4	4	5	4	4	1	2	*1 is lowest OPEX ($/m³ treated)*	*5 is highest OPEX ($/m³ treated)*
	The whole life costs (WLC) of each technology	2	2	1	3	2	1	1	1	4	5	5	4	3	4	3	*1 is lowest WLC over 10 years ($)*	*5 is highest WLC over 10 years ($)*
Environmental and social context	*Final discharge routes (environmental contamination)*	2	2	1	5	3	4	4	4	2	4	3	2	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 included*	*5 is poor allowance and difficult management of final products/ wastes*
Total		**27**	**29**	**24**	**34**	**36**	**34**	**41**	**33**	**32**	**36**	**40**	**31**	**33**	**42**	**39**		

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 final disposal for liquids and solids, have the greatest influence on technology selection and plant design. These factors should be considered along with the recommendations below.

A multi criteria analysis tool has been prepared which allows designer to weight each indicator for importance from 1 to 10 i.e. if 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.

Table 2: Technology selection based on indicators

INDICATOR	BEST FOR	BEST TECHNOLOGY	RATIONAL	RISK WITH CHOICE
Technology	_Easy scale up_	**Upflow Filters**	Can be used on multiple scales. Easy to add more (prefabricated tanks) units in parallel	- Effluent quality To Be Confirmed[11] (TBC) - Area needed for liquid infiltration and solids burial, or additional treatment (to achieve standards)
	Low complexity	**GeoTubes**	Simple technology using local materials	- Effluent quality does not meet public health standards. Needs additional treatment (to achieve standards)
	Footprint area/space i.e. lowest footprint area per m³ treated	**Aeration (centralised) or ABR (for decentralised)**	Lowest footprint area per m³ treated	- Effluent quality TBC - Area needed for liquid infiltration and solids burial, or additional treatment (to achieve standards) - Aeration needs skilled operator and power supply
	Speed of construction and set up	**Upflow Filters**	Prefabricated tanks at ground level so construction is rapid	- Effluent quality TBC - Area needed for liquid infiltration and solids burial, or additional treatment (to achieve standards)
	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	- Effluent quality TBC - Area needed for liquid infiltration and solids burial, or additional treatment (to achieve standards)
	Robustness/stability of process	**Lime**	Lime dose can be adjusted to suit influent. Lime treatment provides full treatment to achieve pathogen kill	- High OPEX
	Treatment effectiveness	**Aeration or lagoons**	Best for public health and environmental effluent standards	- High skills needed to operate
_O&M_	_Skills requirements_	**ABR**	Solids removal every 6 to 12 months otherwise limited maintenance needed	- 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
Cost	_Capital expenditure costs (CAPEX $/m³ treated)_	**ABR**	Lowest capex per m³ treated	- Area needed for solids handling and disposal
	Operational expenditure (OPEX $/year)	**Upflow Filters or Constructed Wetland**	Lowest OPEX per m³ treated	- Effluent quality - Area needed for liquid infiltration and solids burial
	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	- Effluent quality - Area needed for liquid infiltration and solids burial - Scale up difficult for concrete ABR
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	- Effluent quality - Area needed for liquid infiltration and solids burial, or additional treatment (to achieve standards)

(11) 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 slightly different features. Four sites were visited by Arup, two of 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) were using 'assemble on site' type tanks (steel angles 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 Dec/Jan 2019, due to solids blocking the first and second filters), with the first two filters converted to settlement tanks 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 17. 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 filtration tanks. They had two upflow settlement tanks followed by two Upflow Filters. The filter media was coconut husk. Solids were discharged (valve controlled) from the bottom of each tank into soak pits, two per filter, with capacity for two years solids storage i.e. allowing time for adequate pathogen die off. Liquids were disposed to an infiltration trench, 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.

PROCESS FLOW DIAGRAM AND SITE LAYOUT - PLANT 1

Figure 4:
Upflow Filter plant 1 (NGO 1) PFD

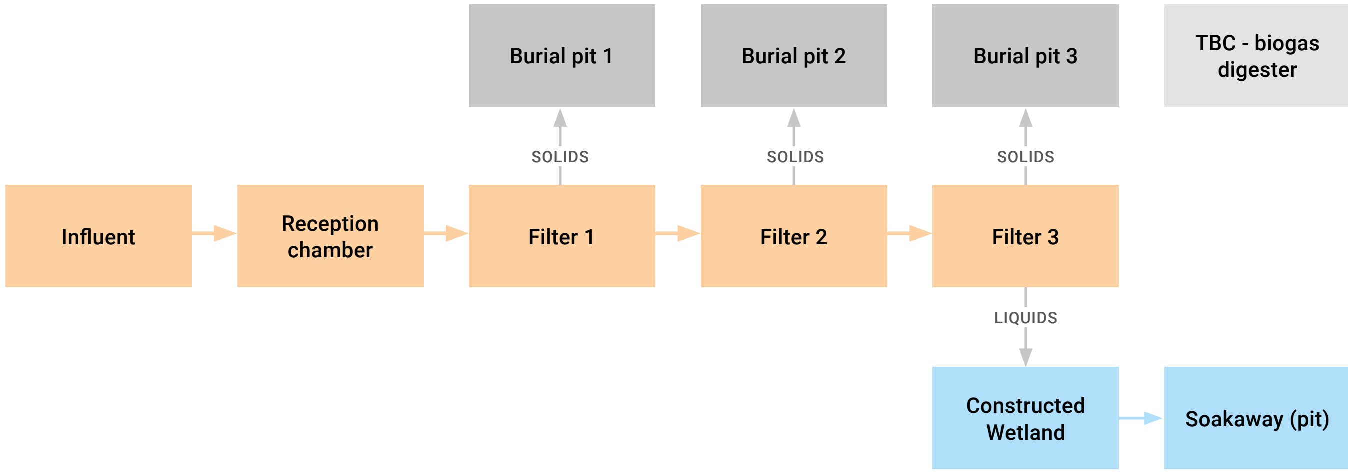


Figure 5:
Site layout plan - Upflow Filter plant 1 (NGO 1)

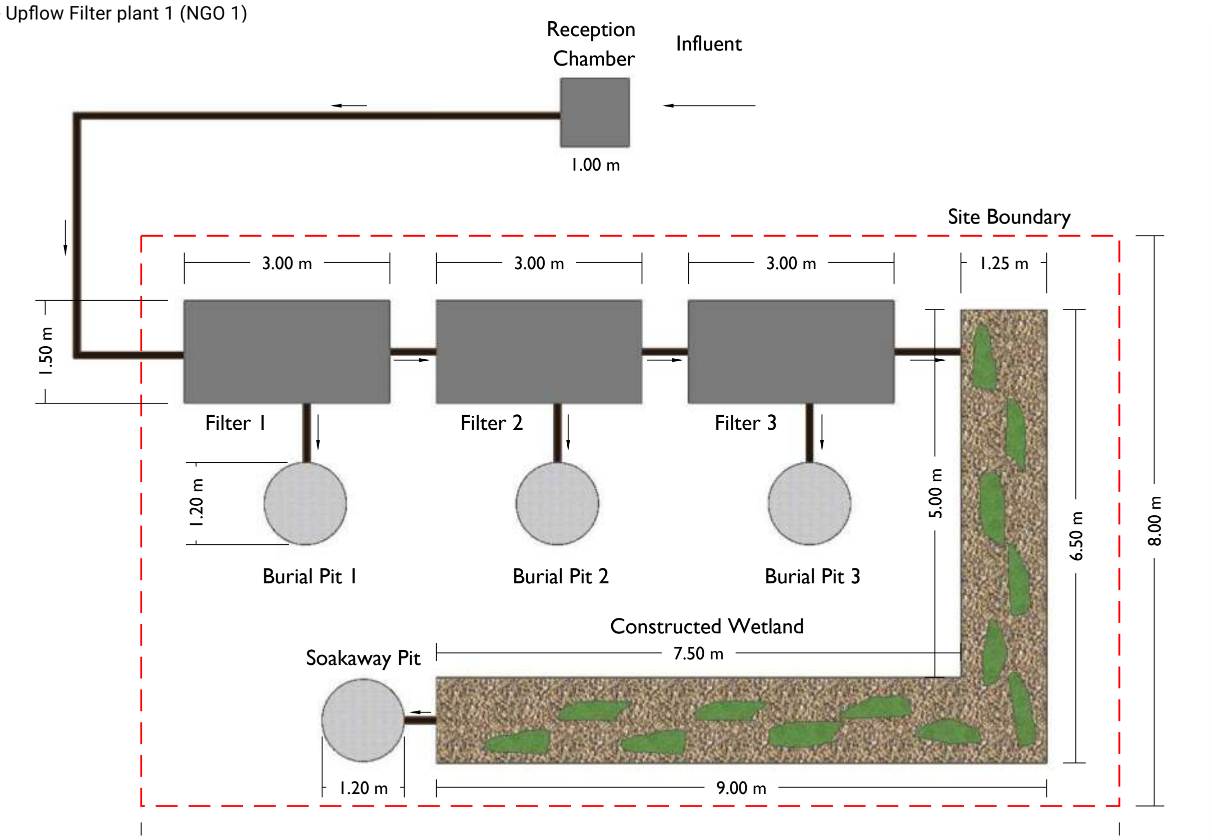
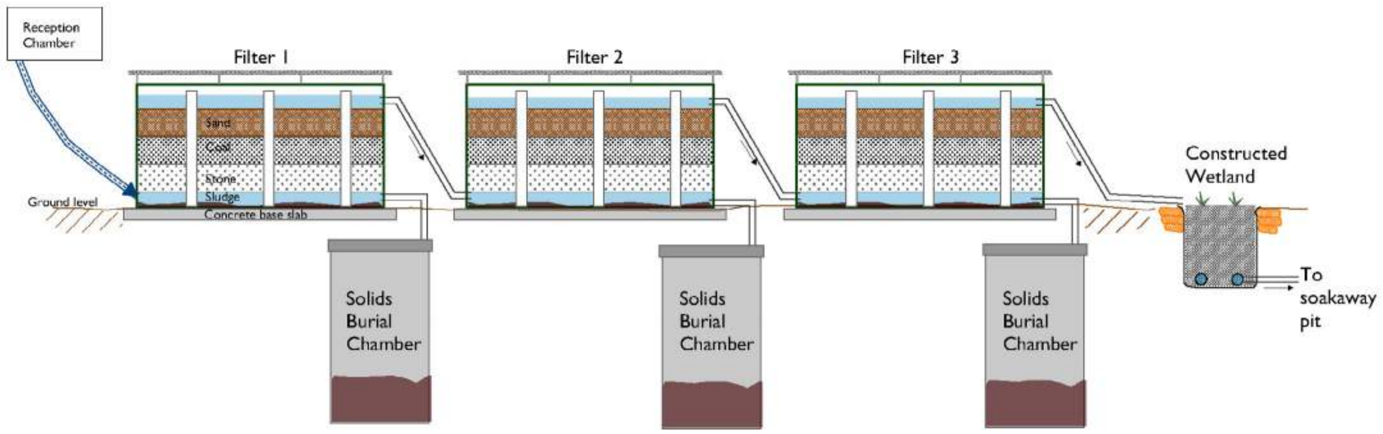


Figure 6:
Upflow Filter plant 1 (NGO 1) cross sections



PHOTOS - PLANT 1

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

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

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA - PLANT 1

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		$5m^3/d$
	Scale/scalability	1	- More settlement tanks and filters could be added in sets of three in parallel
	Footprint area and access	2	- The area for treatment units is $91m^2$ - The site is a total of approximately $110m^2$ - The layout is efficient because rectangular tanks and L shaped CW
	Speed of construction and set up	1	- Civil construction is approx. 1 month (40 labourers and 4 engineers). Plus off site work for filter units (metal and welding). - Metal work comes flat packed and is bolted together on site. - Approximately 20 days to get the process operating
	Resilience to disaster	1	- Soil built up to protect the sites from flooding - All tanks above ground level
TREATMENT PROCESS	**Complexity of treatment process**	1	- Simple, runs by gravity with limited operator intervention - Solids desludging from each filter once per month - Solids emptying every 6 to 12 months. Access to empty soak pits is difficult
	Treatment effectiveness	3	- Initial finding (from UPM) show the systems meet the DoE liquid effluent standards with the exception of Biological Oxygen Demand (BOD), total nitrogen and coliforms. - 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 pit were emptied and disposed to vermiculture or biogas plants operated by the same NGO - Liquid is infiltrated in the soak pit.
OPERATION AND MAINTENANCE	**O and M Skills requirements**	2	- Daily site checks by skilled labour (18 FSM sites in total) - Solids discharge to burial pits once per month - After 1 year operation they found filters blocked, so had to remove & replace media, 1st & 2nd burial pits were full. Hence upgrading to settlement tanks
COSTS	**CAPEX**	5	- $21,420 - $10,710 per m^3 treated
	OPEX	1	- $634 per year - Labour costs only - $0.87/$m^3$ treated
	The whole life costs (WLC)	2	- Assume a plant life of 10 years, assume 90% of materials need to be totally replaced once in that period - $47,000

Good 1 ... 5 Bad

Table 3:
Advantage and disadvantages of Upflow Filters (Plant 1)

PROCESS FLOW DIAGRAM AND SKETCH - **PLANT 2**

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

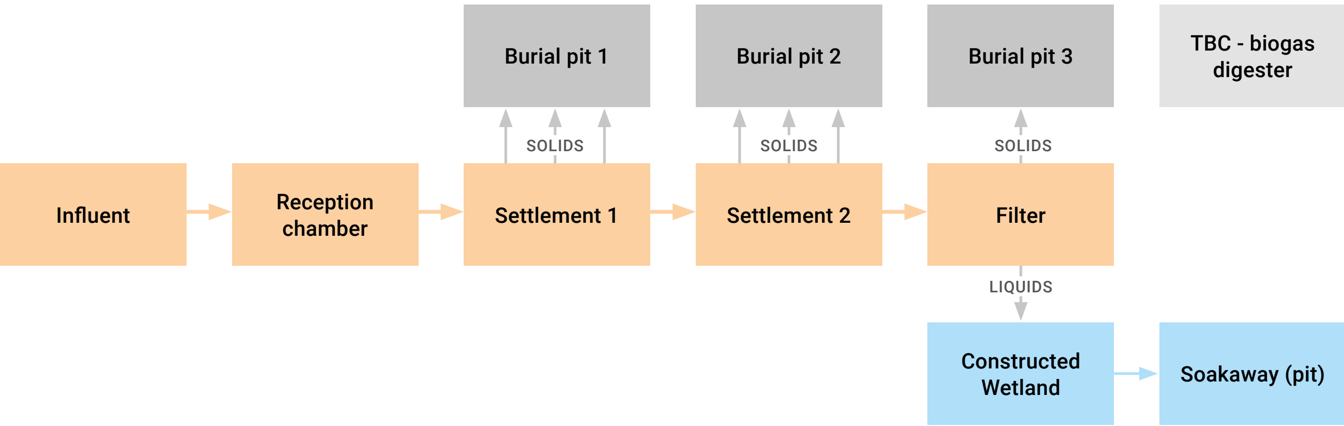


Figure 8:
Site layout plan - Upflow Filter plant 2 (NGO 1)

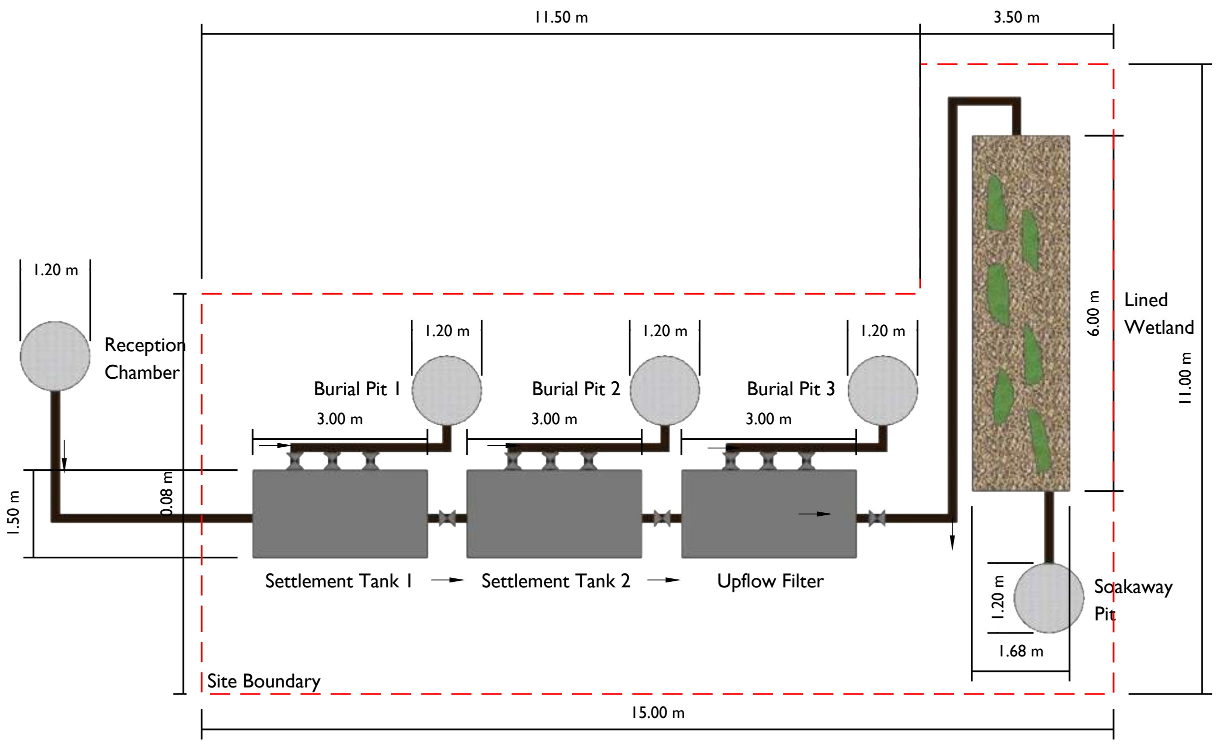
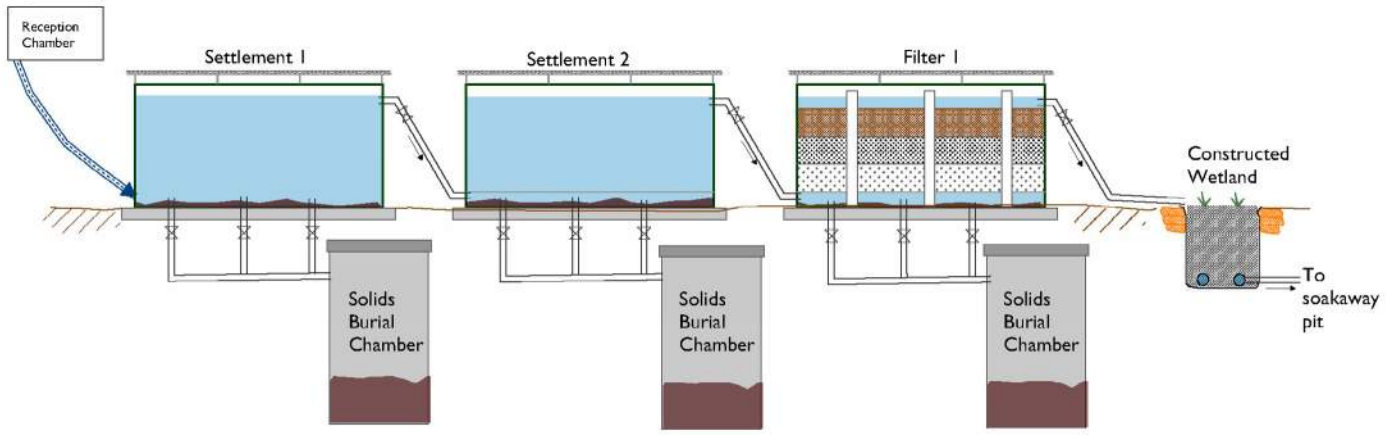


Figure 9:
Upflow Filter plant 2 (NGO 1) cross sections



PHOTOS - **PLANT 2**

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

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

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA - **PLANT 2**

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		5m³/d
	Scale/scalability	1	- More filters could be added in sets of 3 in parallel
	Footprint area and access	2	- The area for treatment units is 91m² - The site is a total of approximately 110m² - The layout is efficient because the filters and wet tank are rectangular
	Speed of construction and set up	1	- Civil construction is approx. 1 month (40 labourers and 4 engineers). Plus off site work for filter units (metal & welding) - Metal work comes flat packed & is bolted together on site - Approximately 20 days to get the process operating
	Resilience to disaster	2	- Soil built up to protect the sites from flooding - All tanks above ground level
TREATMENT PROCESS	**Complexity of treatment process**	3	- Simple, runs by gravity with limited operator intervention - Solids desludging from each filter once per month - Solids emptying every 6 to 12 months. Access to empty soak pits is difficult
	Treatment effectiveness	3	- Initial finding (from UPM) show the systems meet the DoE liquid effluent standards with the exception of Biological Oxygen Demand (BOD), total nitrogen and coliforms - 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 pit were emptied and disposed to vermiculture or biogas plants operated by the same NGO - Liquid is infiltrated in the soak pit
OPERATION AND MAINTENANCE	**O and M Skills requirements**	2	- Daily site checks by skilled labour (18 FSM sites in total) - Solids discharge to burial pits once per month - After 1 year operation they found filters blocked, so had to remove & replace media, 1st & 2nd burial pits were full. Hence upgrading to settlement tanks
COSTS	**CAPEX**	5	- $21,420 - $10,710 per m³ treated
	OPEX	1	- $634 per year - Labour costs only - $0.87/m³ treated
	The whole life costs (WLC)	2	- Assume a plant life of 10 years, assume 90% of materials need to be totally replaced once in that period - $47,000

Good ◀ 1 ● ● ● 5 ▶ Bad

Table 4:
Advantage and disadvantages of Upflow Filters (Plant 2)

PROCESS FLOW DIAGRAM AND SKETCH - **PLANT 3**

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

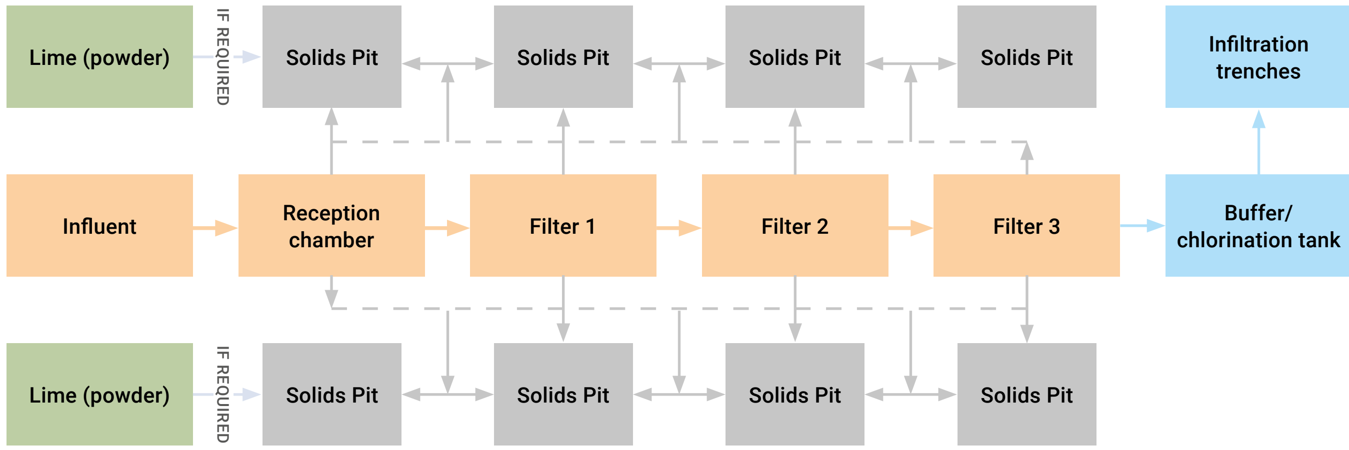
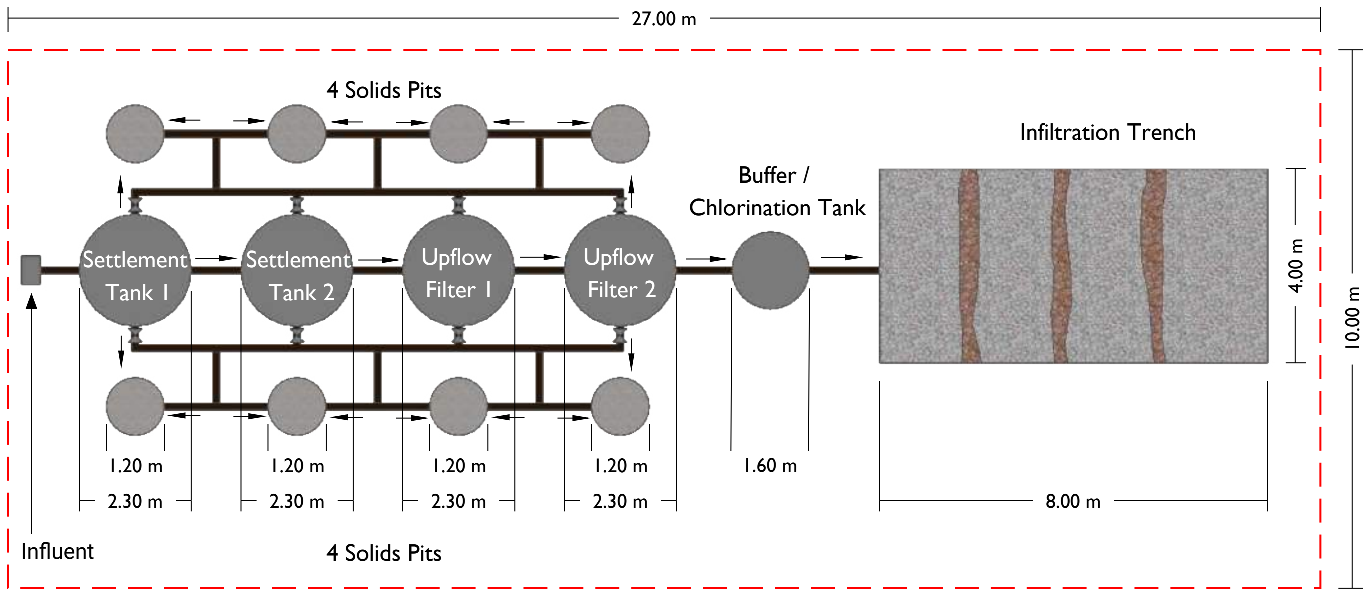


Figure 11:
Site layout plan - Upflow Filter plant 3 (NGO 2)



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

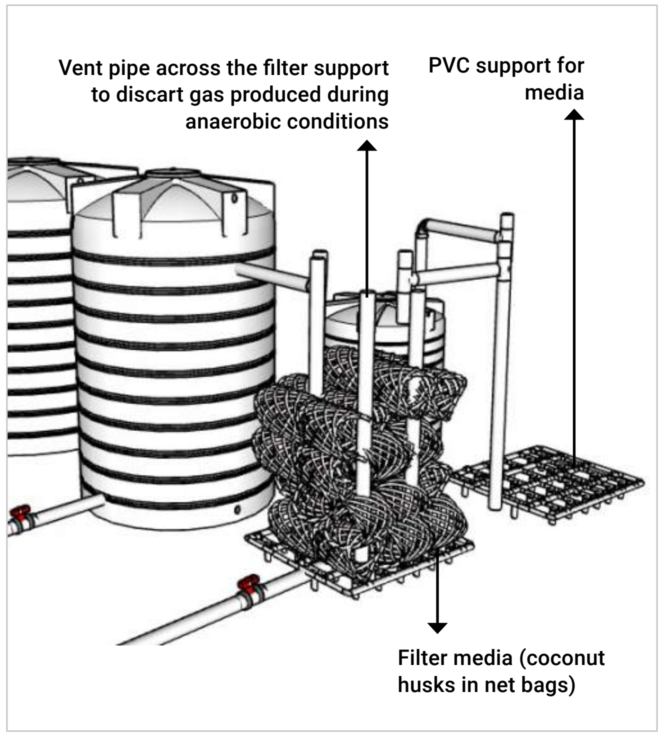


Image 8:
NGO 2 - Sketch showing internal of upflow filter plant 3

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

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA - **PLANT 3**

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		1.75m³/d
	Scale/scalability	1	- More settlement tanks and filters could be added in in parallel
	Footprint area and access	1	- The area for treatment units is 150m² - Layout flexible due to prefabricated tanks - Flexible layout i.e. tanks can be arranged to suit site shape
	Speed of construction and set up	1	- 2 weeks if all the materials area available - Prefabricated plastic tanks
	Resilience to disaster	2	- Prefabricated plastic tanks are not fixed to a base so maybe unstable in flood or earthquake Design modifications could be made to overcome this
TREATMENT PROCESS	**Complexity of treatment process**	3	- Simple, runs by gravity with limited operator intervention - Solids desludging from each filter once per month - Solids emptying every 2 years. Access to empty soak pits is difficult
	Treatment effectiveness	2	- No test data available - Pathogen kill achieved through disinfection (for liquid) and storage time for solids i.e. 12 months - There are two solids pits per tank to allow one to rest whilst other is in use
	Pinch point	3	- Liquid infiltration i.e. infiltration capacity of 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 to infiltration trench which appeared to be adequately sized - Solids to storage pit and then can be used as soil improver/compost - Solids pits can be shallower and wider if high GWL
OPERATION AND MAINTENANCE	**O and M Skills requirements**	2	- Plant runs by gravity - One skilled labour twice per week to carry out regular check - Solids emptying 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 cholera outbreak
COSTS	**CAPEX**	4	- $9,000 - $5,150 per m³ treated
	OPEX	1	- $575 per year - Labour costs only - $0.90/m³ treated
	The whole life costs (WLC)	1	- Assume a plant life of 10 years, assume 80% of materials need to be totally replaced once in that period - $21,957

Good 1 ... 5 Bad

Table 5:
Advantage and disadvantages of Upflow Filters (Plant 3)

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.

GeoTubes are 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 flexihose) into the GeoTubes. Solids are retained within the tube, 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) limit 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, which dictated how many GeoTubes they had. Having several GeoTubes at one site gave the flexibility in 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 GeoTube as they had found that felt type geotextile blocked quickly. There was a high level of solids carry over evident from the GeoTubes to the primary filter. The NGO were aware and working on improvements to overcome this.

The infiltration bed also appeared to be overwhelmed with solids blockage 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 solids of the GeoTube influent and also achieve greater overall removal efficiencies for pathogens. The GeoTubes would be kept as a secondary treatment process to further treat the liquid effluent from the ABR.

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

PROCESS FLOW DIAGRAM AND SKETCH

Figure 12:
GeoTube PFD

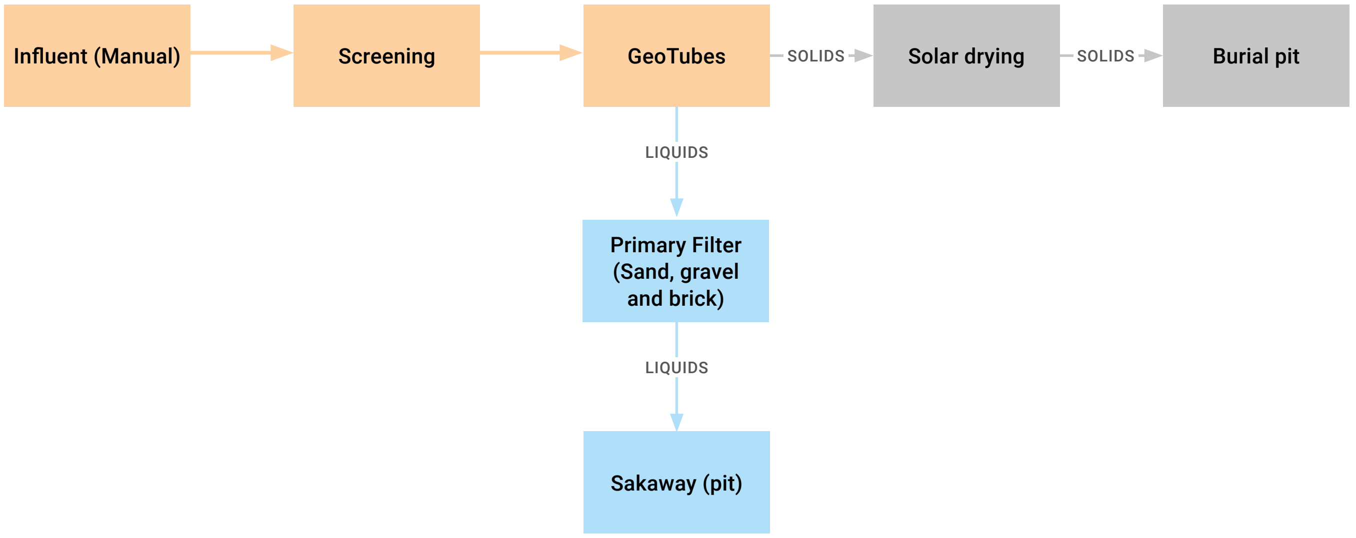
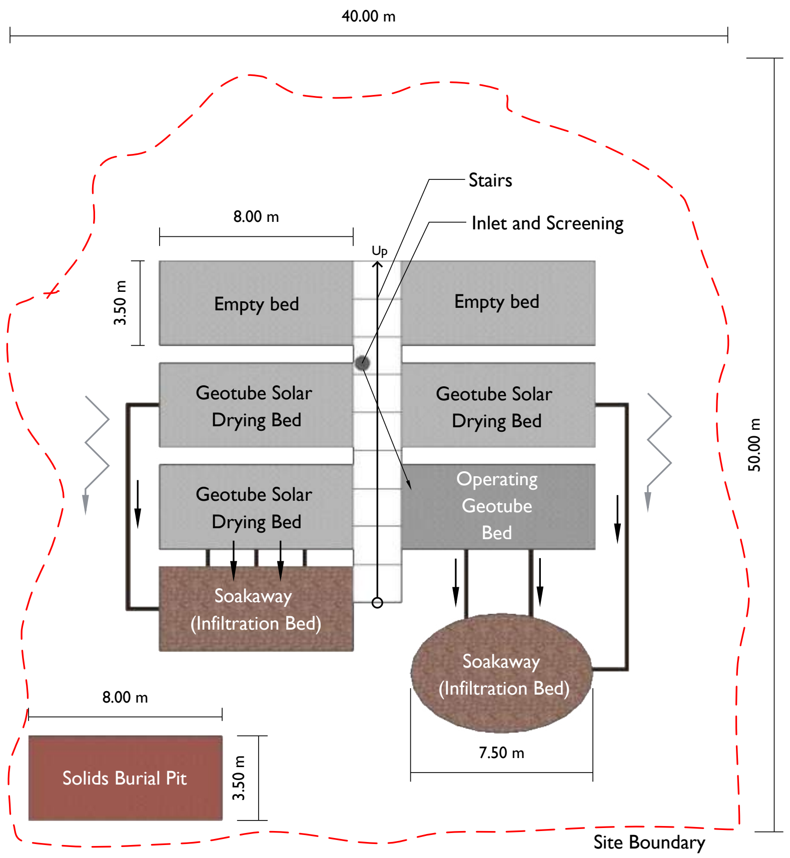
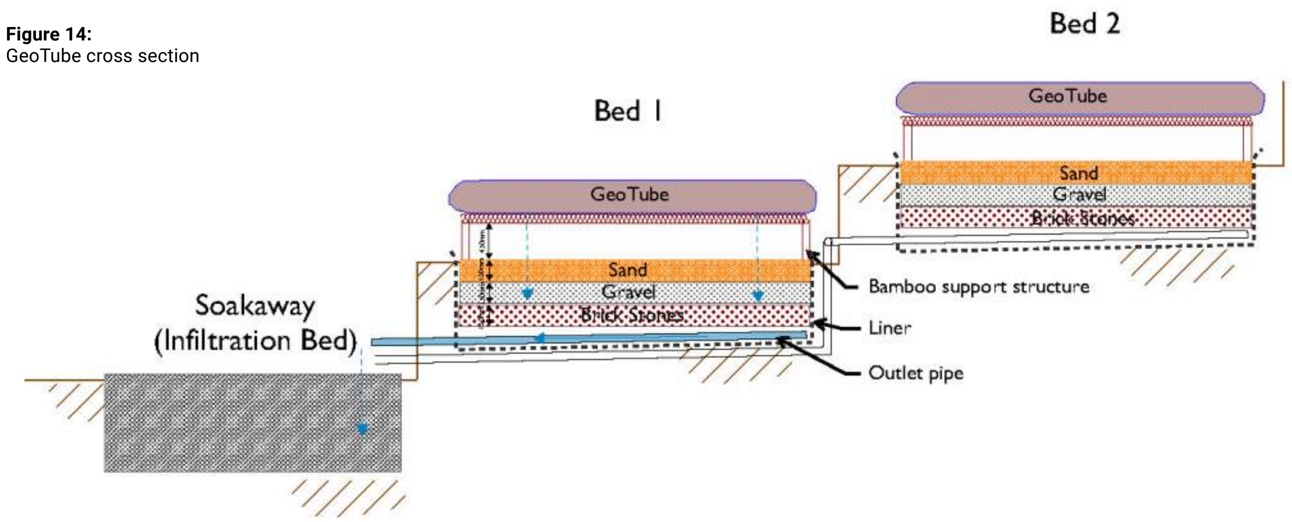


Figure 13:
Site layout plan - GeoTube



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 7 m^3/d - It was estimated to serve 440 population - Rotation (GeoTube filling, drying, 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 was suitable weight to use bamboo structures and also for ease of solids emptying - Process can be scaled up by adding more GeoTubes
	Footprint area and access	2	- Each GeoTube bed is 28m^2 i.e. 8×3.5m. One is used at a time - Whole Site was 2,000m^2 i.e. 40×50m - Flows are by gravity so preferable to have a natural fall on the site or elevate the inlet screen and GeoTube to achieve gravity flows
	Speed of construction and set up	2	- Construction 1.5 months with 20 people - Setting up process is simple i.e. can start straight away - Large amount of ground work (slope cutting and stability)
	Resilience to disaster	5	- Limited flood resistance - GeoTube support structure could be designed to resist flood i.e. raised or within walls - CXB site on a steep slope i.e. slope stability issues - GeoTube and bamboo supports simple to repair
TREATMENT PROCESS	**Complexity of treatment process**	1	- Simple two stage process i.e. solids/liquids separation and liquid filtration
	Treatment effectiveness	5	- Initial findings from UPM testing shows 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 (i.e. no lime and poor liquid management with poor infiltration) it would be classed as 'unacceptable' under the CXB FSM strategy - With the planned improvements for example addition of an ABR upstream and a properly designed liquid infiltration downstream, then the site would be 'acceptable' under the CXB FSM strategy
	Pinch point	3	- Solids are buried within FSM site (fenced area). Relatively informal but NGO are working to improve - Liquids are infiltrated but system was overwhelmed and there was ponding on site
	Final discharge routes	5	- Liquid to infiltration trench which appeared to be adequacy sized - Solids to storage pit and then can be used as soil improver/compost - Solids pits can be shallower and wider if high GWL
OPERATION AND MAINTENANCE	**O and M Skills requirements**	3	- Daily site maintenance tasks - setting up influent pipework, clearing inlet screen, operating valves etc - 3 to 4 site staff (not including desludging)
COSTS	**CAPEX**	1	- $1,300 per GeoTube bag including construction costs i.e approx. - $5,200 for whole site with 4No. GeoTubes plus solids and liquid filter and disposal - $200 per m^3 treated
	OPEX	3	- Approximately $6,700 per year mainly for labour (3 to 4 site staff per day) - Approximately $2.80 per m^3 treated
	The whole life costs (WLC)	3	- $70,677

Good 1 5 Bad

Table 6:
Advantage 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. Of the two sites visited one was poorly managed so results have been excluded from this section, they are presented in the comparison in Appendix B.

Vertical subsurface flow CW are typically a lined bund or bed, filled with filter media (e.g. graded gravel or stone) with a top layer of soil, 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 such a time to achieve biochemical stabilisation and pathogens die off. Liquids are filtered as they drain through the bed media, separating out remaining solids. A certain amount of biological treatment by microorganisms also occurs within the CW. Generally, liquids require further treatment prior to disposal (to protect environment and public health).

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

The plants visited had not been operated for long enough to see any solids accumulation. The operating NGO noted that they can rake off solids when required and dispose to land e.g. buried or used as a soil conditioner/compost. As there is only one CW bed at each site this limits flexibility in operation to cope with solids i.e. you cannot stop feeding the plant and allow the pathogen die off period in the solids. If two beds were operated in parallel allowance for solids storage and degradation could be included.

The CW visited were within an excavated bund, 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. 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 using sandbags and geotextiles.

PROCESS FLOW DIAGRAM AND SKETCH

Figure 15:
PFD - Constructed Wetland

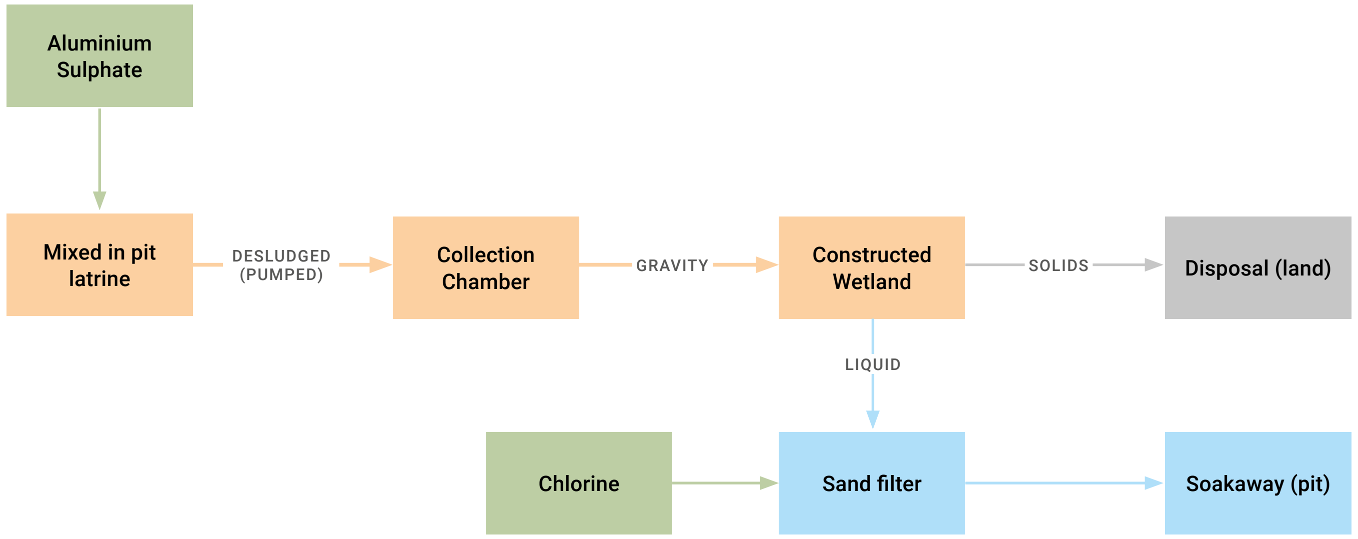
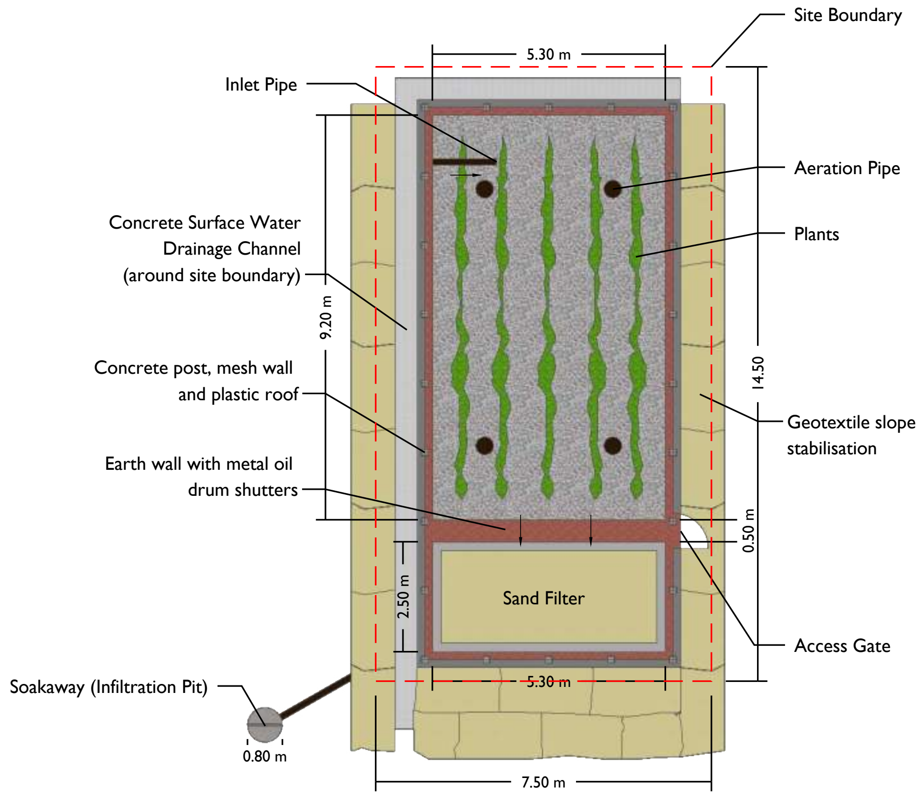
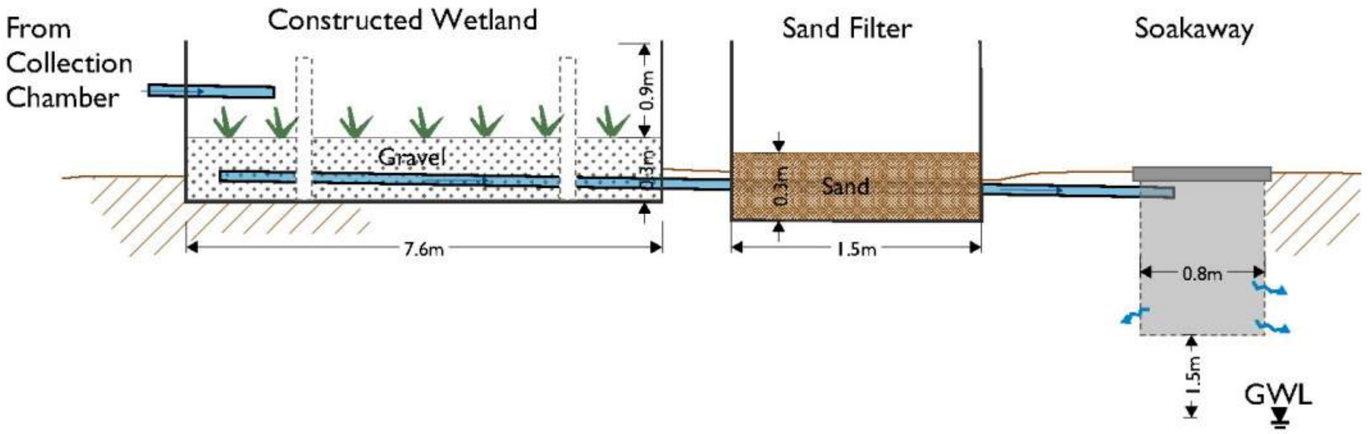


Figure 16:
Site layout plan - Constructed Wetland



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/week (1.4 m³/d) - Estimated as 1000 population equivalent P.E.
	Scale/scalability	3	- CW have a relatively large footprint area per volume treated - The CW technology can be scaled up to municipal scale however the area required will be the limiting factor - Care is need at larger scale to ensure good distribution of influent and avoid short circuiting - Large-scale CW are normally made up of smaller CW beds with alternating use
	Footprint area and access	4	- Sites were 60 to 80m² total area i.e. 56 (m²/m³ treated)[12] - Sites were compact and fully enclosed (fenced) - Steep terrain with only pedestrian access
	Speed of construction and set up	3	- Construction period is approximal 1 month – predominantly site stabilisation and excavation - Commissioning takes 2 months to establish plants and microorganisms with the CW. However, it can take up to 6 months to achieve acceptable removal efficiencies (for BOD, pathogens and nutrients)
	Resilience to disaster	3	- CXB examples had walls raised to 1m AGL surrounding the plant hence it is protected from surface water flooding - Simple excavated bunds etc are relatively resilient to earthquake
TREATMENT PROCESS	**Complexity of treatment process**	3	- The treatment process is relatively simple, with the main process having two stages; CW 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	2	- 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 CW) stored and disposed to land - Liquids disinfected and infiltrated. Need to ensure infiltration is adequately sized
OPERATION AND MAINTENANCE	**O and M Skills requirements**	1	- Each plant was fed once per week by the latrine desludging team - Nine CWs are managed by a team of 10 people - Disinfection (chlorination) is conducted once per week into the sand filter - The CW itself has limited operational requirements, (operates by gravity) - Periodic replacement of plants is required - No experience of solids removal – likely to be once per year but depends on design
COSTS	**CAPEX**	4	- $11,340 construction costs including labour - $8,000 per m³ treated
	OPEX	3	- $1,500/year (excluding desludging costs, includes labour, new plants, chlorine) - $2.85 per m³ treated
	The whole life costs (WLC)	2	- £36,330, assuming a plant life of 10 years, assume 90% of materials need to be totally replaced once in that period

Good ◂ 1 ● ● ● 5 ▸ Bad

Table 7:
Advantage and disadvantages of Constructed wetlands

(12) Literature suggests that for "normal wastewater treatment" in warm climates vertical flow CWs need 1.2m² per person i.e. for 1000 P.E 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.)

Biogas

DESCRIPTION

A number of biogas system have been constructed by an NGO in the registered camp two or three years ago. The systems ranged in size from 2m³ to 4m³. 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 by gravity to an intermediate pit. The pit 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 gas generation process slows down 2/3rd 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 infiltration or connected to a site drain.

A vactug desludging pump is used to remove accumulated solids from the digestion chamber, approximately every 4 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.

PROCESS FLOW DIAGRAM AND SKETCH

Figure 18:
PFD - Biogas

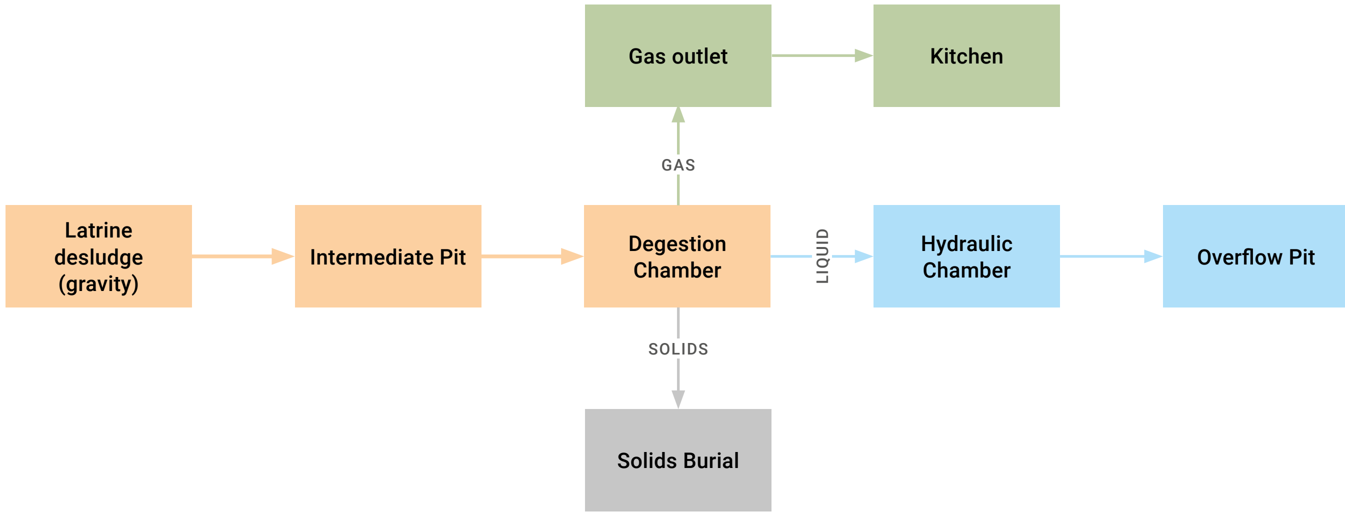
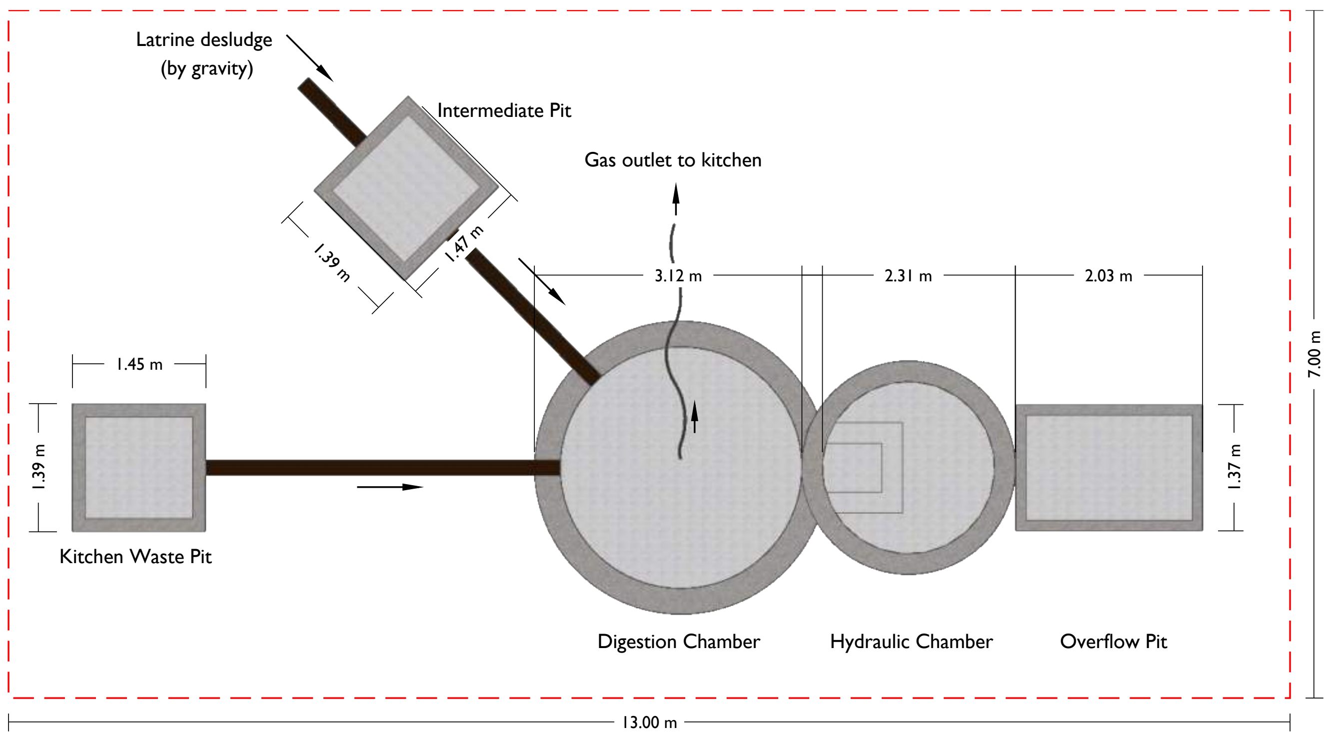


Figure 19:
Site layout plan - Biogas



PHOTOS

Image 17:
4m³ concrete biogas digester

Image 18:
Hydraulic Chamber

Image 19:
Biogas kitchen

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		- $4m^3/d$ - $2m^3/d$ sites also visited
	Scale/scalability	4	- Not easily scalable for a decentralised model - Prefabricated digesters come in a variety of sizes but likely maximum 8m³ would be efficient for "household" type scale, otherwise you look to develop a centralised type plant - Size of biogas reactor (digester) need to be aligned with volume of influent i.e toilet blocks not individual latrine - A 4m³ digester serves a kitchen shared by six families. This would need to be scaled accordingly
	Footprint area and access	3	- 36m² - 9m²/m³ treated
	Speed of construction & set up	4	- Construction 1 to 2 months, depending on if prefabricated tanks are used - 40 days after initial commissioning until gas is enough to use in the kitchen
	Resilience to disaster	4	- Tanks are below ground - Risk that gas storage is damaged in earthquake
TREATMENT PROCESS	**Complexity of treatment process**	4	- Plant operates with minimal staff - Relatively complex to control the biological process - Sensitive to changes in influent characteristics but experience (last 2 to 3 years) has shown there are limited changes and the system has been functioning ok
	Treatment effectiveness	3	- 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 to 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
	(plant) Pinch point	3	- Liquid storage (hydraulic chamber) and disposal
	Final discharge routes	4	- Liquid infiltrated or discharged to drain. Evidence at some sites - Solids removal every 4 months or when gas production slows. Not clear where these are disposed to (another site?). 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 - sometime more frequent - Cleaning crew 13 people (also look after 37 plants) - Desludging every 4 to 12 months
COSTS	**CAPEX**	2	- $3,655 treated or $914 per m³ treated
	OPEX	1	- $84/yr or $0.06 per m³ treated
	The whole life costs (WLC)	1	- Assume a plant life of 10 years, assume 40% of materials need to be to replace once in that period. A majority is concrete, so limited replacement is required (although dependant on context and quality) is required - $6,000

Good 1 5 Bad

Table 8:
Advantage and disadvantages of Biogas

Anaerobic Baffled Reactor

DESCRIPTION

An Anaerobic Baffled Reactor (ABR) (also known as a upflow anaerobic filter) comprises of a pre-treatment settlement zone followed by several stages of up-flow filtration operated under anaerobic conditions. 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 layer at the bottom of each chamber.

ABRs do not provided 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 or need appropriate disposal e.g. incineration or burial. This should be considered when planning an ABR system.

A NGO had recently constructed an ABR in camp 17. The ABR has settlement chamber followed by a baffled rector tank which facilities further solids/liquids separation by settlement. Settled solids are retained in the settler and baffled tank and removed periodically (e.g. once per year). Liquid flows to a further treatment by a graded gravel filter followed by a polishing pond with an overflow to the local surface watercourse.

Solids are retained within the settlement chamber and baffled tank, some digestion occurs reducing the volume, however this still needs 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 have time before the first solids removal to create a solids storage/burial area.

The ABR is 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.

PROCESS FLOW DIAGRAM AND SKETCH

Figure 20:
PFD - ABR

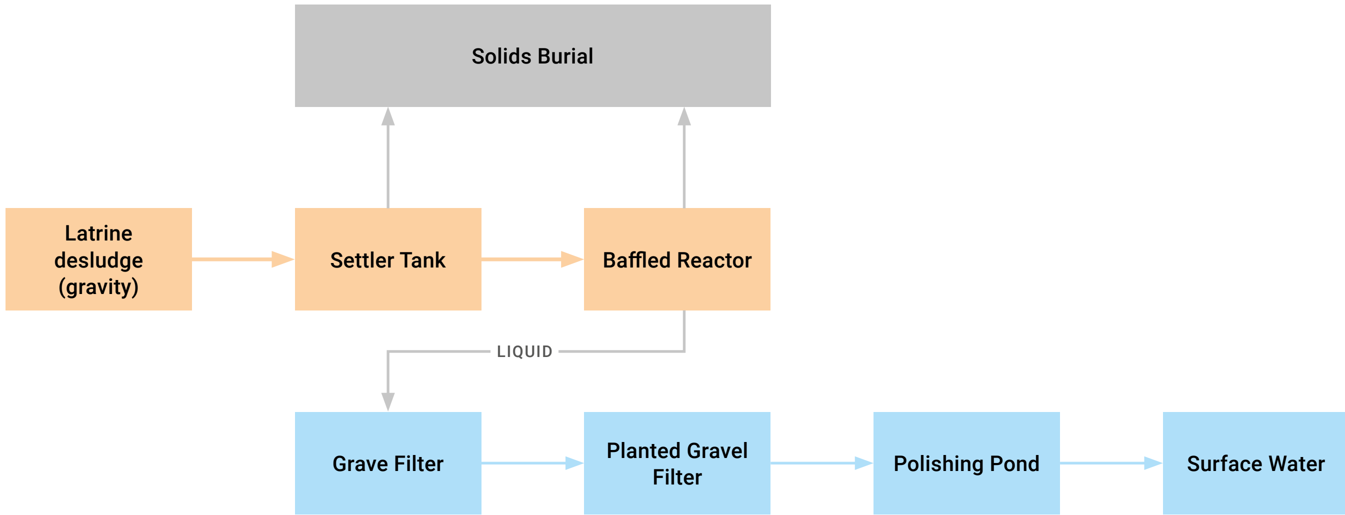
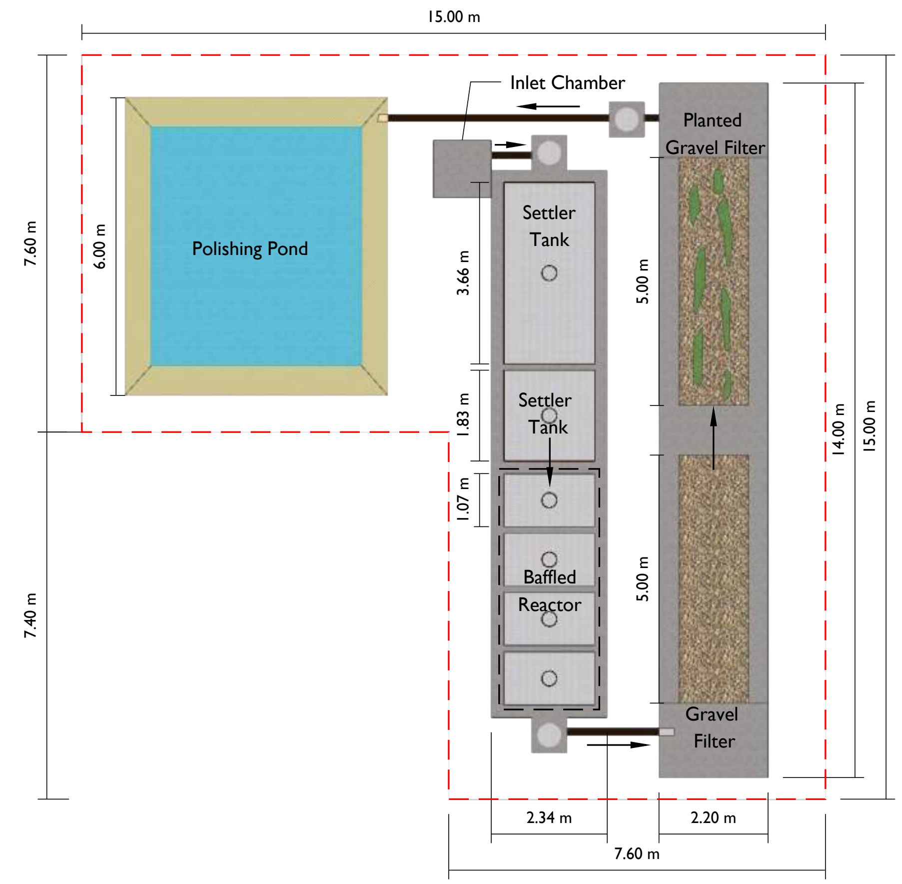


Figure 21:
Site layout plan - ABR



DECENTRALISED CHEMICAL TREATMENT: **ANAEROBIC BAFFLED REACTOR**

PHOTOS

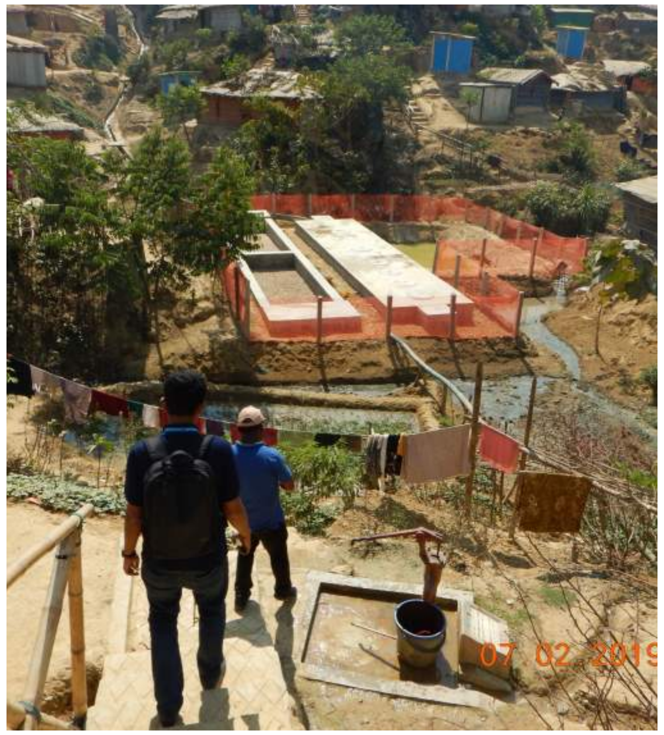


Image 20:
ABR general site view

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**		- $35m^3$/d. Only operational since end January 2019
	Scale/scalability	4	- Not modular i.e. scale up only possible at design stage
	Footprint area and access	4	- Treatment units $185m^2$ - $5.3m^2/m^3$ treated - Pedestrian access
	Speed of construction and set up	3	- Excavation and concrete construction needed. Structure is relatively complicated i.e. 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**	3	- Relatively simple and robust i.e. not reliant on biological treatment - Solids/liquids separation by settlement - Anaerobic digestion of solids - Liquid filtration
	Treatment effectiveness	3	- No testing had been conducted of 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 to human health was met for both solids and liquid effluents - The (WHO 2006) helminth standard was not met for with solids or liquid effluent
	Pinch point	3	- Liquid infiltration & solids storage (within and outside of ABR)
	Final discharge routes	4	- Liquids are discharged to the polishing ponds (with fish) where it evaporates or overflows to local surface watercourse - No solids management 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 and M Skills requirements**	1	- Very little maintenance of ABR needed - Desludging in camp every 4 days so ABR is fed every 4 days - 1 skilled labourer? every 4 days to check site - Desludging every 4 to 12 months (depending on observed accumulation rate). Assume will take 2 to 3 days to empty and handle solids (drying and burial)
COSTS	**CAPEX**		- $12,000 - $342/m³ treated
	OPEX	1	- $800/yr - $0.06/m³ treated
	The whole life costs (WLC)	1	- Assume a plant life of 10 years, assume 40% of materials need to be to replaced once in that period. A majority is concrete so not much replacement is required - £21,160

Good 1 … 5 Bad

Table 9:
Advantage and disadvantages of ABRs

Lime

DESCRIPTION

Seven lime treatment sites were visited across the camps, all were decentralised (chemical) treatment. These were operated by five different NGOs, each system operated by an NGO i.e. five systems, are described in the following sections and summarised in table 10.

Lime treatment achieves pathogen reduction by raising the pH of the FS to over 11 for 30 minutes to 1 hour. Each NGO had tried to optimise the lime dose to achieve this. Each had slightly different method and infrastructure to achieve this. A PFD of each site and a site layout are shown Figure 18 to Figure 27.

Lime dosing rate was generally 20 kg per m^3 of FS, this is higher than the rate literature suggests (by approximately three times). This is thought to be due to the quality of the lime powder (calcium hydroxide Ca(OH2)) 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 streams also differed slightly between sites. Some (good and bad) features of each are noted below.

Lime sites 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 (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 resident, 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 test 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 to land i.e. buried or used locally as soil conditioner/compost. Solids should be stored for a minimum 12 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.

(UPM) testing had 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 the lime treatment reduces to the final quality and prevents any pathogen regrowth. This site diluted the lime powder in (1:1 with) water 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 pathogen exposure of workers. 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 with the final products.

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, 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.

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

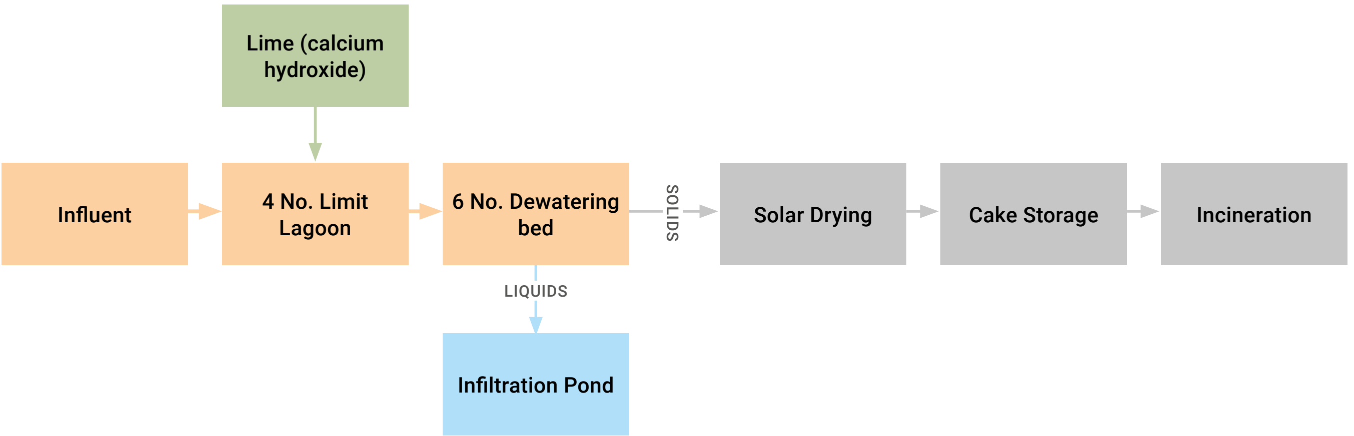
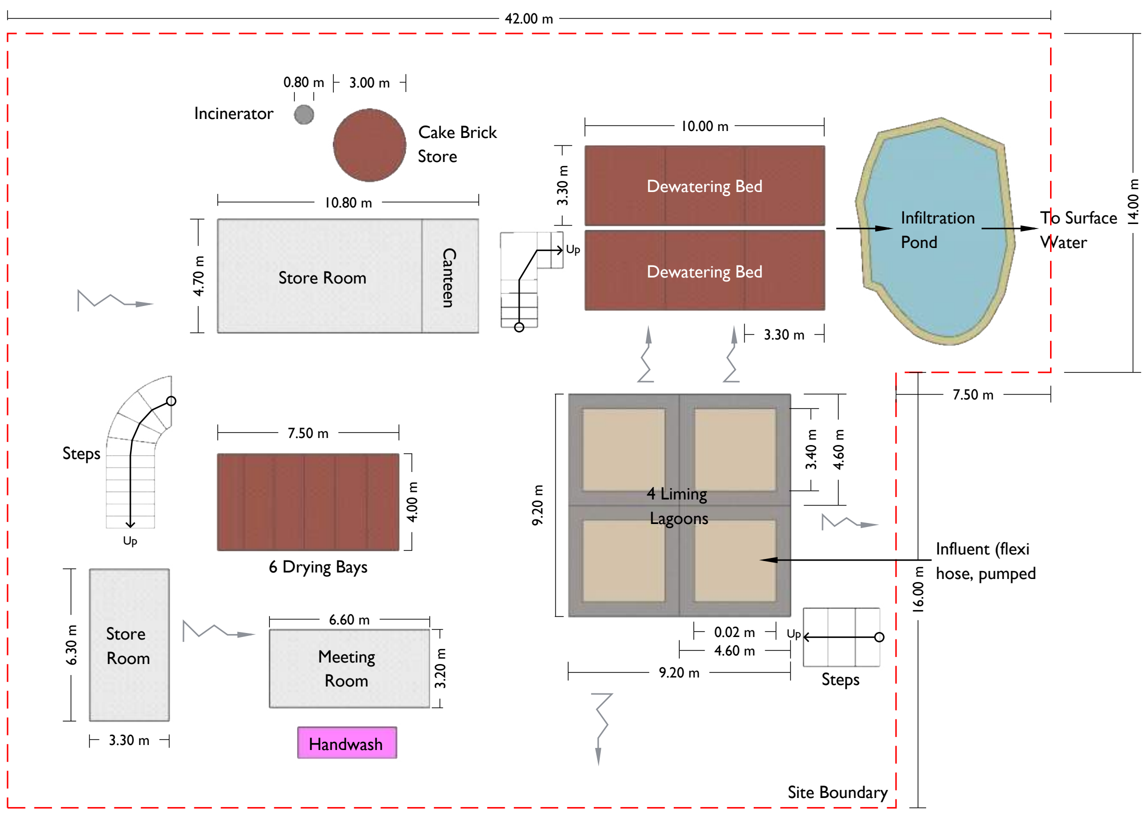


Figure 23:
Site layout plan - Lime 1



DECENTRALISED CHEMICAL TREATMENT: **LIME**

PHOTOS - **LIME 1**

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

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**		- 40m³/d
	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	3	- Treatment units 300m² - 53m²/m³ treated - Pedestrian access
	Speed of construction and set up	2	- Commissioning is fast - good for rapid response to emergency. Chemical treatment does not require time to activate treatment i.e. no biological growth stage - 1 month. Manual labour 20 people. No large civil structures
	Resilience to disaster	2	- Elevated site so flood resistant. No large civil structures so (relatively) earthquake resistant.
TREATMENT PROCESS	**Complexity of treatment process**	2	- Simple process. Lime dose 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	3	- Classed as 'acceptable under CXB FSM strategy - UPM data show WHO (reuse) standards are met for coliform (E.coli), however helminths still present - DoE COD and BOD standards are not met
	Pinch point	3	- Dewatering bed area - Liquid disposal - infiltration capacity
	Final discharge routes	2	- Incineration of solids - good disposal route. Heat could be used e.g. for heating water or drying sludge, but this would add complexity to operation
OPERATION AND MAINTENANCE	**O and M Skills requirements**	3	- 1 engineer per day plus unskilled labour - FSM plant 6 people for 3 days plus 1 security guard and 1 engineer
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	- Approx. $21,350 per year including labour, fuel for pumping and lime. - $10 per m³ treated
	The whole life costs (WLC)	4	- WLC $221,170 - Bamboo superstructures have 2 to 3 year life. This has been included in the CAPEX repeats - Assumed 80% of materials need to be totally replaced once in 10 year period

Good 1 ... 5 Bad

Table 11:
Advantage and disadvantages of Lime (1)

DECENTRALISED CHEMICAL TREATMENT: **LIME**

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

Figure 24:
PFD - Lime 2

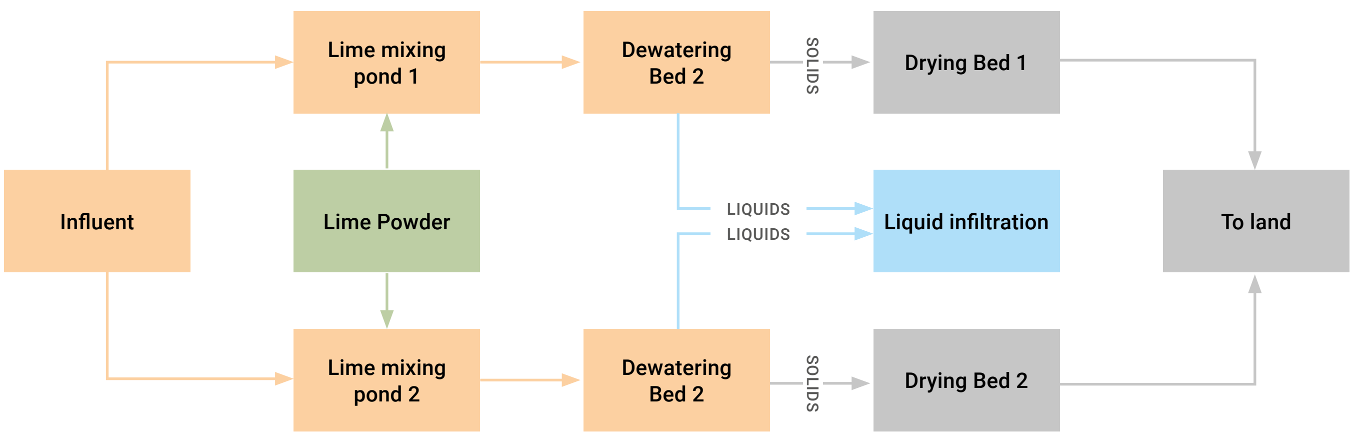
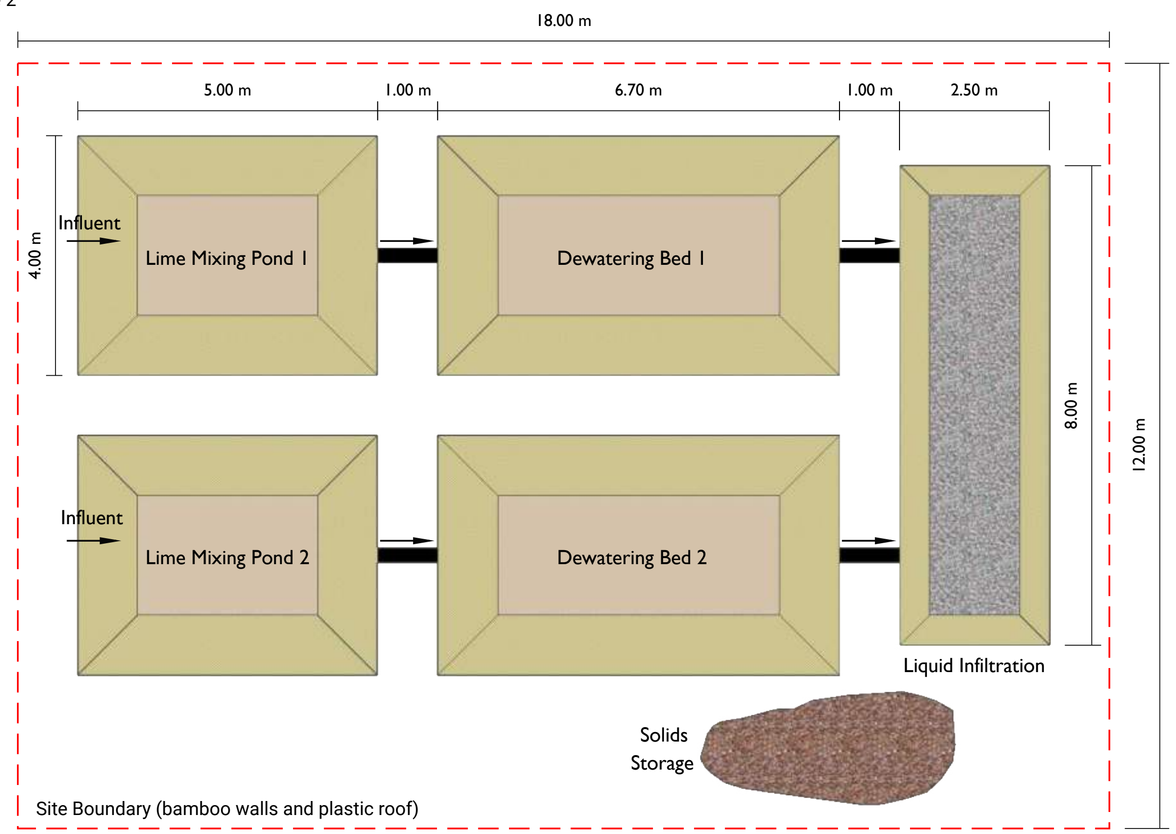


Figure 25:
Site layout plan - Lime 2



PHOTOS - LIME 2

Image 28:
Lime 2 - Lime mixing lagoon

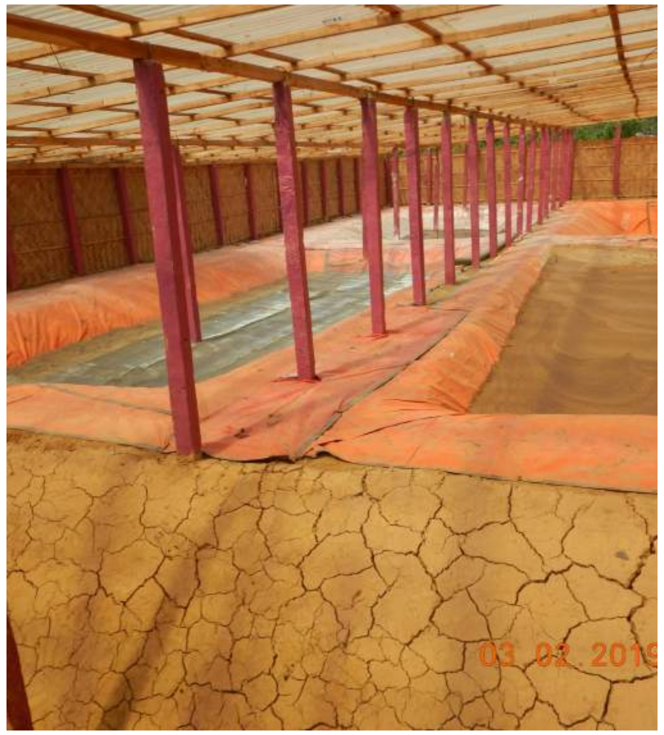


Image 29:
Lime 2 - Dewatering beds

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**		- $11m^3/d$
	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	3	- Treatment units $200m^2$ - $18m^2/m^3$ treated - Pedestrian and vehicle access
	Speed of construction and set up	2	- Commissioning is fast - good for rapid response to emergency. Chemical treatment does not require time to activate treatment i.e. no biological growth stage - 1 month
	Resilience to disaster	2	- No large civil structures so (relatively) earthquake resistant - No slope stabilisation in ponds i.e. may be susceptible to earthquake
TREATMENT PROCESS	**Complexity of treatment process**	2	- Simple process. Lime dose quick to monitor and adjust - Process units laid out in flow order making it simple to understand and operate - Simple – two stages plus solids and liquids disposal
	Treatment effectiveness	4	- 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 and M Skills requirements**	3	- FSM plant 2 to 3 "unskilled" people per day to mix lime and remove solids from dewatering bed - Plus 2 engineers per camp
COSTS	**CAPEX**	2	- Approx. $10,710 - $975 per m^3 treated
	OPEX	4	- Approx. $37,975 per year including labour, fuel for pumping and lime - $9 per m^3 treated
	The whole life costs (WLC)	5	- WLC $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 10 year period

Good 1 5 Bad

Table 12:
Advantage and disadvantages of Lime (2)

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

Figure 26:
PFD - Lime 3

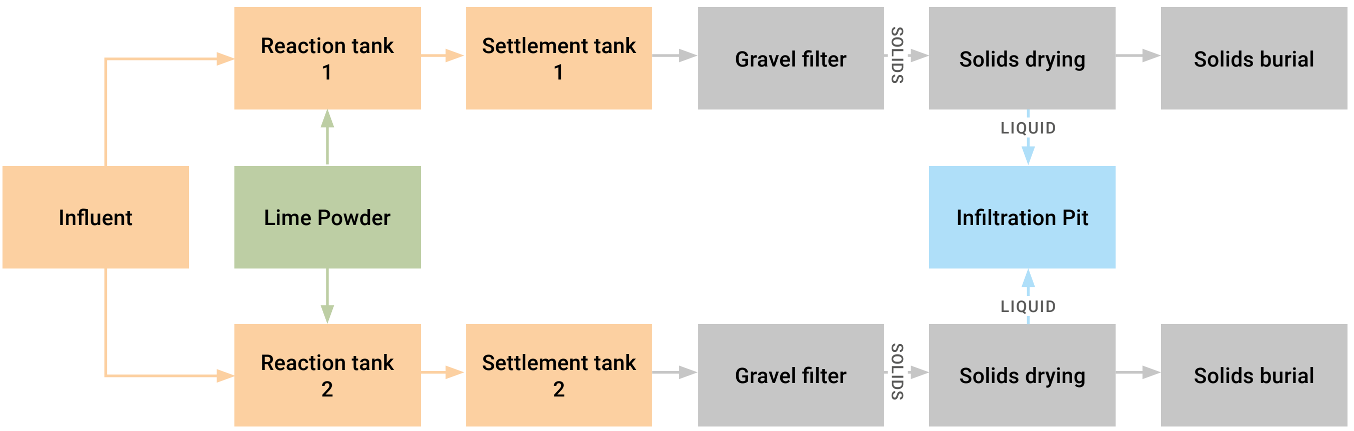
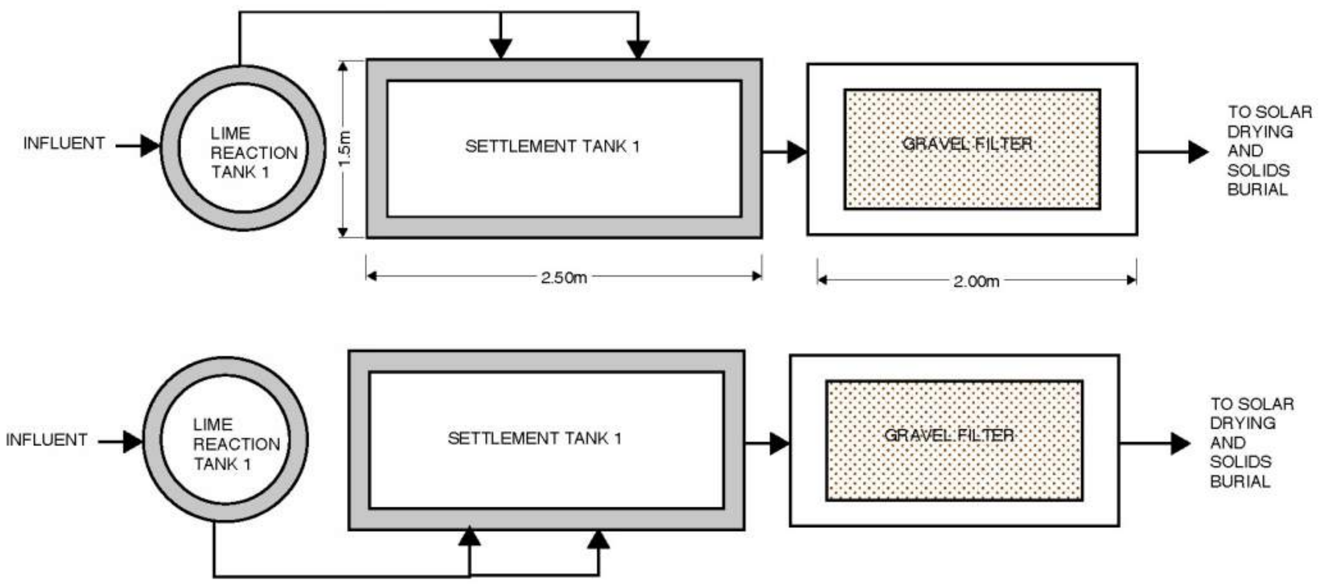


Figure 27:
Site layout plan - Lime 3



PHOTOS - **LIME 3**

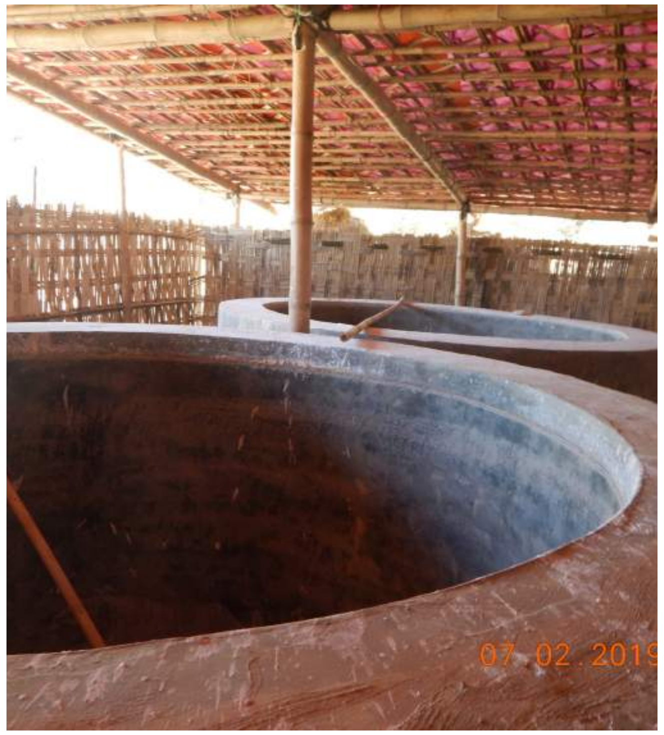


Image 32:
Lime 3 - Lime mixing/reactor tanks

Image 33:
Lime 3 - Settlement tank

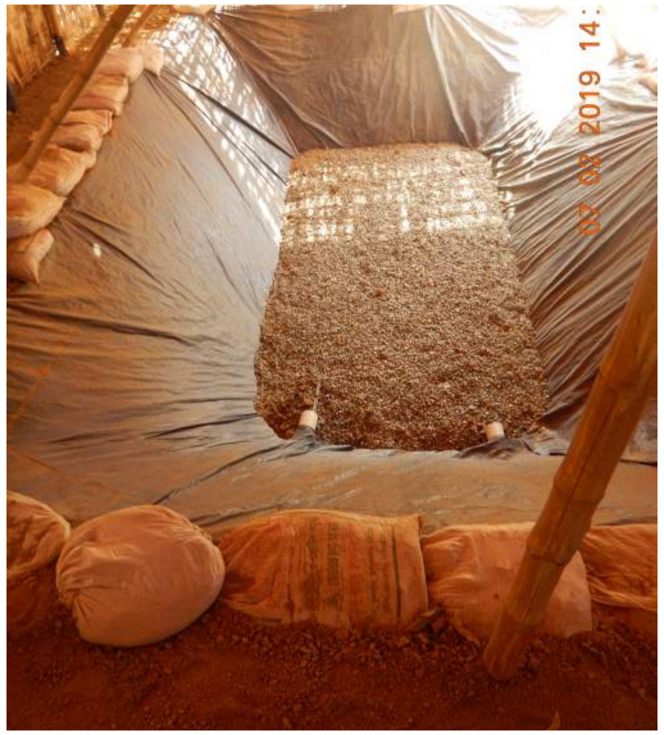


Image 34:
Lime 3 - Gravel filter/dewatering bed

Image 35:
Solids storage area (under construction)

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA - LIME 3

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	Capacity		- $3.7m^3/d$
	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 $130m^2$ - $35m^2/m^3$ treated - Pedestrian access
	Speed of construction and set up	4	- Commissioning is fast - good for rapid response to emergency. Chemical treatment does not require time to activate treatment i.e. no biological growth stage - 2 to 3 months construction
	Resilience to disaster	3	- Concrete structures. Settlement tanks are below ground level so maybe susceptible to flooding - however site location not in a flooding location
TREATMENT PROCESS	Complexity of treatment process	2	- Simple - three stages plus solids and liquids disposal - Process units laid out in flow order making it simple to understand and operate
	Treatment effectiveness	3	- Classed as 'acceptable under CXB FSM strategy - No test data available - Liquids infiltration and solids burial control exposure risk
	Pinch point	3	- TBC plant had just started operation. Solids drying area looked small
	Final discharge routes	3	- Liquids infiltrated - but infiltration pit is on a steep slope - Solids handling (drying) was under construction
OPERATION AND MAINTENANCE	O and M Skills requirements	3	- FSM plant 4 "unskilled" people per day, every 3 days - Plus 2 supervisors per camp
COSTS	CAPEX	3	- $7,435 - $2,000 per m^3 treated
	OPEX	5	- Approx. $41,270 per year - Relatively high due to cost of lime and lime dosing not optimised - $30 per m^3 treated
	The whole life costs (WLC)	5	- WLC $420,881 - Concrete structures have 20yr+ design life so good WLC/limited CAPEX repeats - Assumed 10% of materials need to be totally replaced once in 10 year period

Good ◀ 1 ● ● ● 5 ▶ Bad

Table 13:
Advantage and disadvantages of Lime (3)

PROCESS FLOW DIAGRAM AND SITE LAYOUT PLANS - LIME 4

Figure 28:
PFD - Lime 4

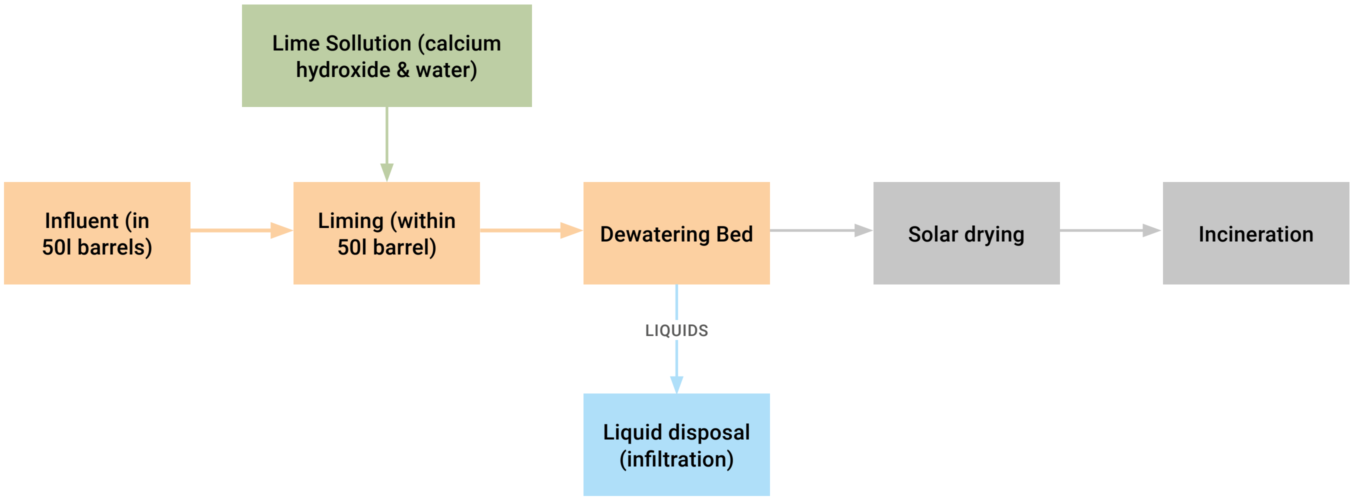
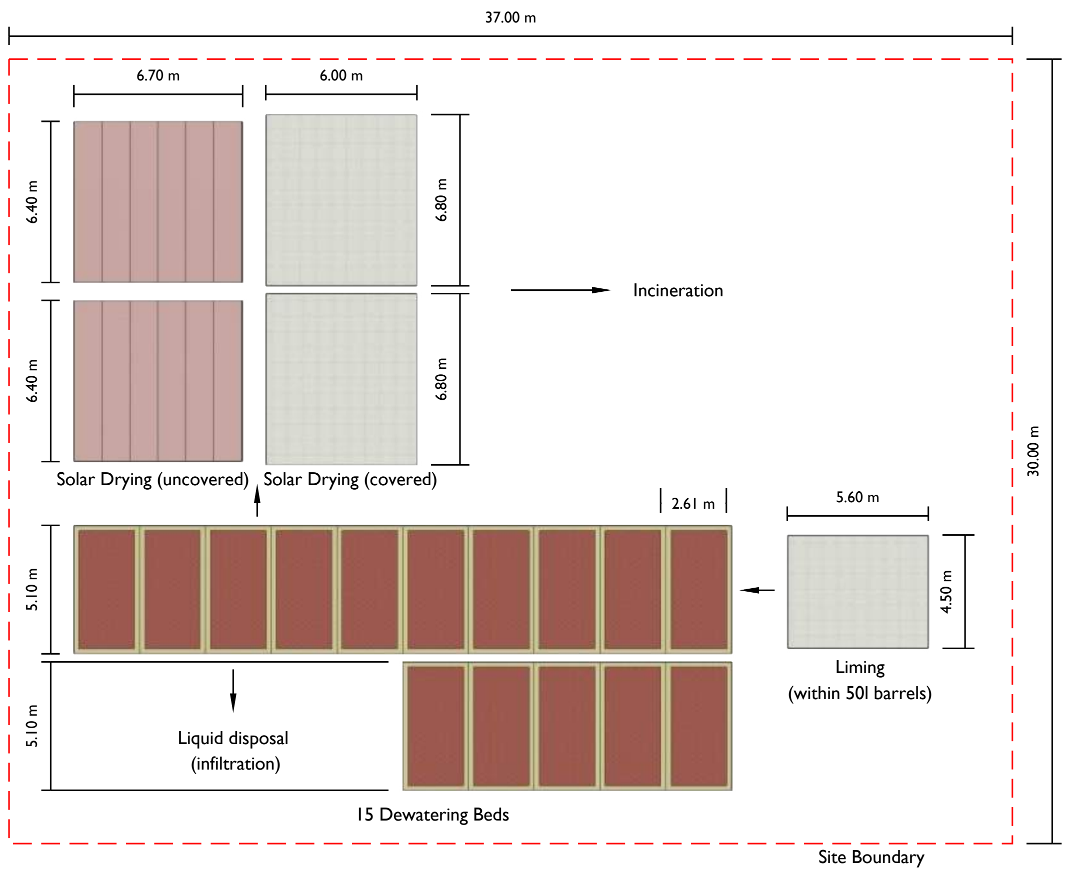


Figure 29:
Site layout plan - Lime 4



PHOTOS - LIME 4

Image 36:
Lime 4 - Lime mixing area

Image 37:
Lime 4 - Drying racks

Image 38:
Dewatering Bed

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA - LIME 4

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		- $4m^3/d$
	Scale / scalability	2	- Scale up of 'in-barrel' mixing is simple and will not require much more area. Barrels can also be stacked - Dewatering can with additional beds (simple excavated soil)
	Footprint area and access	2	- Treatment units $150m^2$ - $38m^2/m^3$ treated - Pedestrian access
	Speed of construction and set up	2	- Commissioning is fast - good for rapid response to emergency. Chemical treatment does not require time to activate treatment 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 at ground level i.e. excavated with no edge build up so susceptible to flooding
TREATMENT PROCESS	**Complexity of treatment process**	2	- Mixing in barrels allows stringent quality control and is simple to get lime dose correct or to adjust - Simple two stage process followed by solids disposal
	Treatment effectiveness	2	- Classed as 'acceptable under CXB FSM strategy - (UPM) testing showed that WHO (reuse) standards for both final liquid and solids. A majority of the DoE standards are met with the expectation of COD and BOD
	Pinch point	3	- Dewatering bed area - especially in the wet season as 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 and M Skills requirements**	3	- 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 m^3 treated
	OPEX	4	- Approx. $22,118 per year or $15 per m^3 treated
	The whole life costs (WLC)	4	- WLC $238,590 - All bamboo superstructures have 2 to 3 year life) - Assumed 150% of materials need to be totally replaced once in 10 year period i.e. some bamboo structures replaced more than once over 10 years

Good ◀ 1 ● ● ● 5 ▶ Bad

Table 14:
Advantage and disadvantages of Lime (4)

DECENTRALISED CHEMICAL TREATMENT: **LIME**

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

Figure 30:
PFD - Lime 5

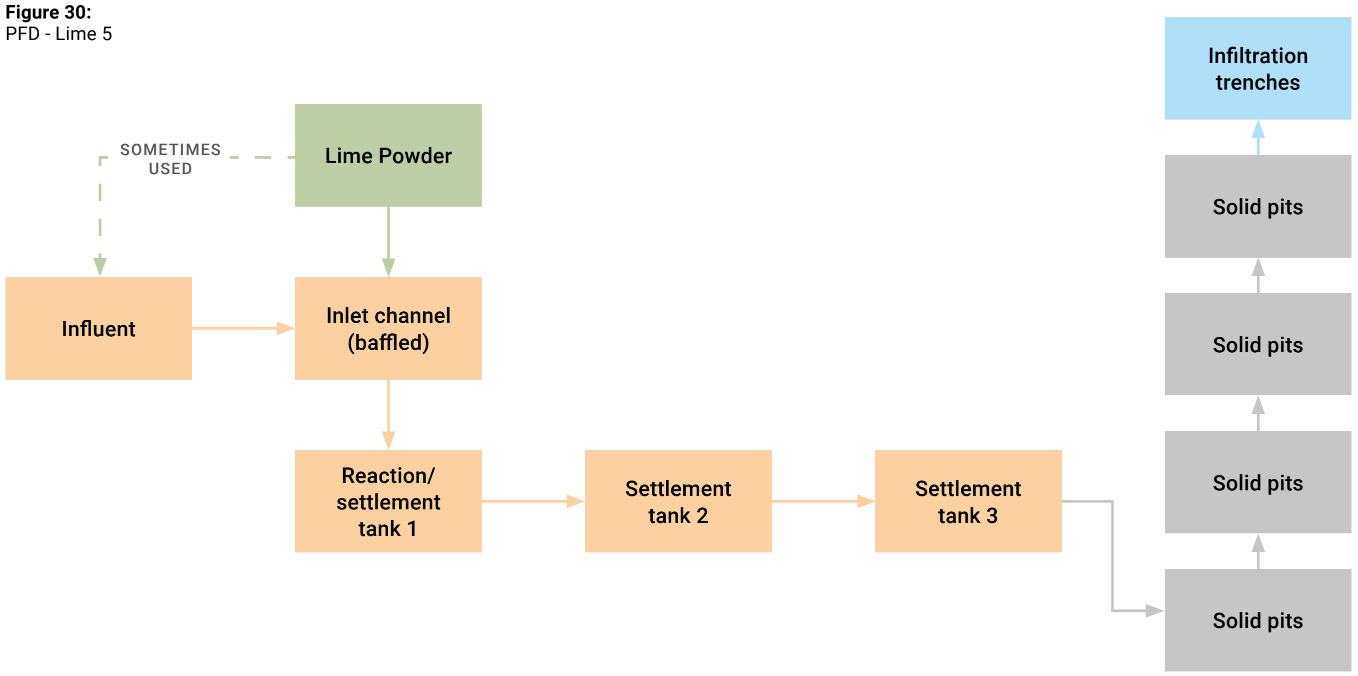
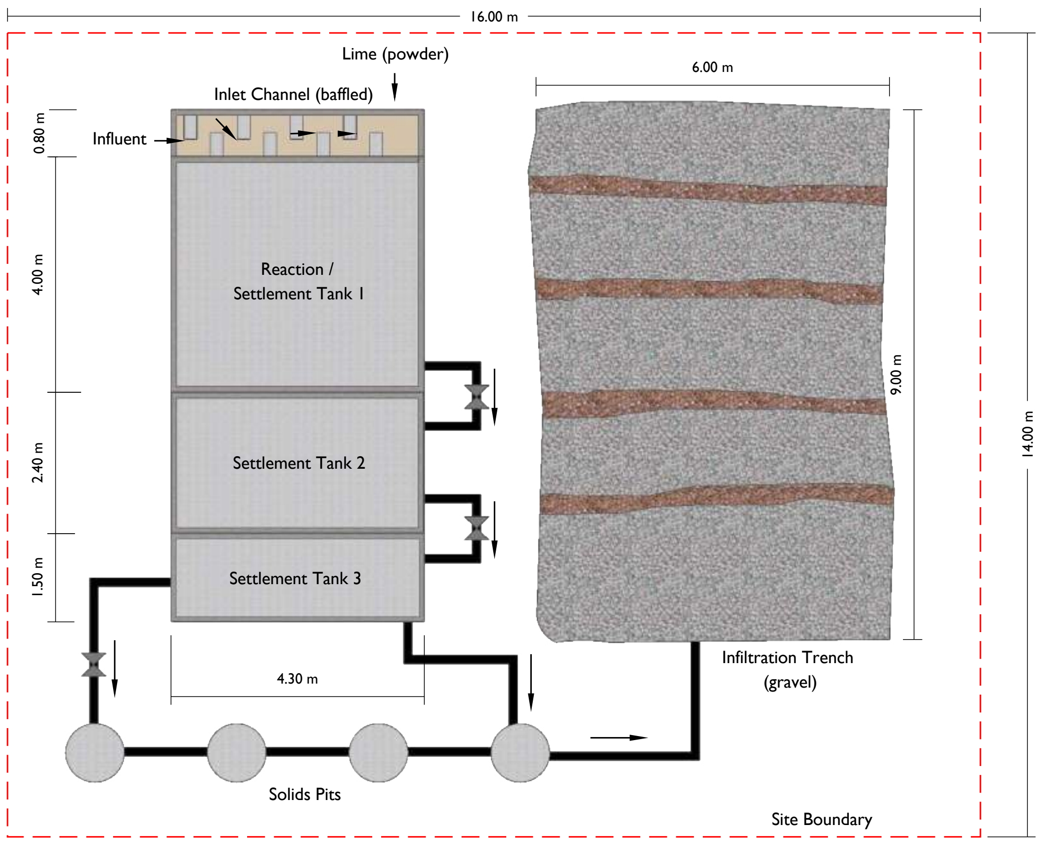


Figure 31:
Site layout plan - Lime 5



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**		- 2.7m³/d
	Scale/scalability	4	- Concrete/brick structure of set dimensions. Size increase could affect the lime mixing efficiency and increase risk of solids build up in a (difficult to access) tank
	Footprint area and access	3	- Treatment units 110m² - 41m²/m³ treated - Pedestrian access
	Speed of construction and set up	3	- Commissioning is fast - good for rapid response to emergency. Chemical treatment does not require time to activate treatment i.e. no biological growth stage - 2 months to construct 14 plants, approx. 2 weeks to construct one
	Resilience to disaster	2	- Raised above flood level and concrete/brick structures so resistant to flooding - (Rigid) Civil structures may be susceptible to earthquake
TREATMENT PROCESS	**Complexity of treatment process**	1	- Simple process. Lime dose quick to monitor and adjust. - Limited operator intervention needed e.g. mixing achieved as a function of discharging sludge to at inlet channel, flow control valves operated every 3 days - Solids and liquids separated by gravity and flow to the disposal site
	Treatment effectiveness	3	- Classed as 'acceptable under CXB FSM strategy - ph 11 to 11.5 targeted, 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 and M Skills requirements**	2	- Unskilled with one engineer per camp to supervise - Low labour requirement (1 person every 3 days)
COSTS	**CAPEX**	3	- $4,235 - $1,570 per m³ treated
	OPEX	4	- Approx. $10,000 per year low labour cost (1 person every 3 days) - $10 per m³ treated
	The whole life costs (WLC)	3	- $105,600 assumed 10% of materials need to be totally replaced once in 10 year period - Civil structures are brick and concrete so have 10yr+ design life i.e. no CAPEX repeats

Good ◂ 1 ● ● ● 5 ▸ Bad

Table 15:
Advantage and disadvantages of Lime (5)

6.7 CENTRALISED BIOLOGICAL TREATMENT: **ANAEROBIC LAGOONS**

Anaerobic Lagoons

DESCRIPTION

Anaerobic Lagoons are centralised biological FSM plant located in camp 4 extension constructed and operated by one NGO. The FSM plant has a capacity of 60m^3/day[15] and takes a 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 tanker (with 2No. 5,000 litre tanks) or via a series of pumps and intermediate tanks with a final gravity line to the inlet screens. No limed sludge is accepted to the site due 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 approx. 45 days (based on information from BORDA) which allows settlement and also 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 on to the polishing pond. The final effluent is discharged via a meandering outlet channel to a local surface watercourse. This allows time and surface area for effluent to oxygenate prior to discharge.

Solids storage within the lagoons is sized for 1.5 years (based on assumed influent sludge characteristics). When required, the solids will be emptied onto a planted drying bed (to be constructed under phase 2) with drain liquid returned to the liquid treatment stream. The drying bed allows storage of solids for approximately 1 year which allows for stabilisation and pathogen die off. After which 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.

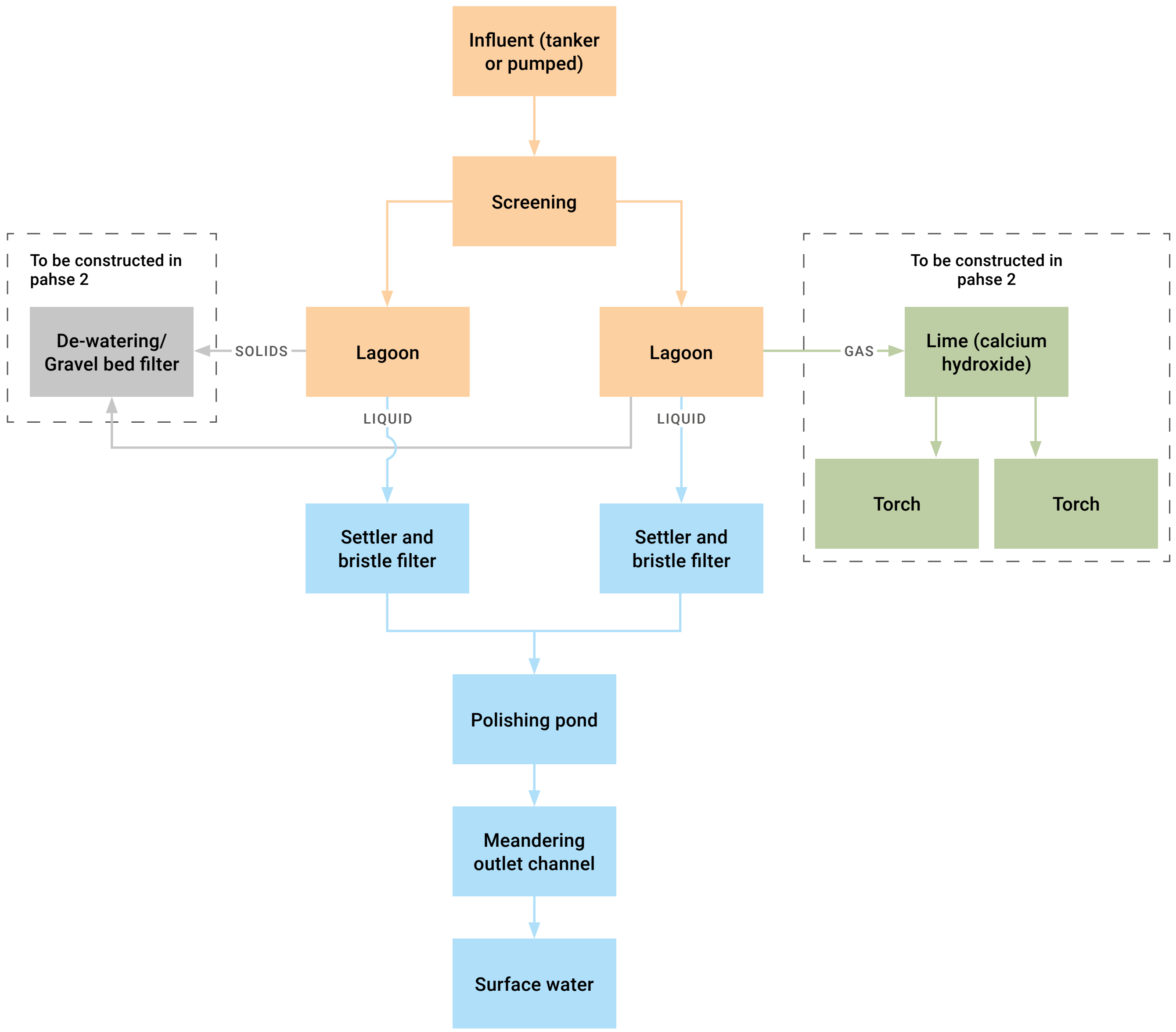
A PFD and site layout plan are shown in Figure 32 and Figure 33.

(15) 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 60m3/d. This means that phase 1 of the plant (solids liquid separation and liquid treatment) has some spare capacity in addition to 60m3/d.

CENTRALISED BIOLOGICAL TREATMENT: **ANAEROBIC LAGOONS**

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:
Anerobic Lagoon

CENTRALISED BIOLOGICAL TREATMENT: **ANAEROBIC LAGOONS**

PHOTOS

Image 47:
Sedimenter 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**		- $60m^3$/day
	Scale/scalability	5	- Centralised treatment process, scale up possible by adding new treatment units (e.g. anaerobic lagoons) in parallel - Expansion space allocated for additional 3No. Anaerobic lagoons (same size as existing) - Smaller sized anaerobic lagoons could be constructed but the minimum scale is still a 'centralised system'.
	Footprint area and access	4	- Area for treatment units is approximately $4,800m^2$ - Whole site area $74,000m^2$, 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 set up	5	- Construction 6 months + - Construction relatively long due to scale - The lagoons and polishing pond are large excavated structures with lined with clay (local material) and plastic (imported)
	Resilience to disaster	3	- Excavated/earth structures so relatively resistant to earth quake and simple to repair (compared to concrete structures) - CXB site location is resistant to flooding
TREATMENT PROCESS	**Complexity of treatment process**	3	- Relatively simple i.e. liquid has 2 main process with limited operator requirements - Biological process can be sensitive to incoming sludge characteristics. Oxfam are testing all incoming sludges from other NGOs
	Treatment effectiveness	2	- Site commissioned in January 2019 so no quality data - Retention time will allow for settlement and pathogen die off
	Pinch point		- TBC after some time of operation
	Final discharge routes	1	- Liquid to surface water - Solids via planted drying bed (to be constructed under phase 2)
OPERATION AND MAINTENANCE	**O and M Skills requirements**	3	- 3 skilled staff to operate FSM site including a mechanic - Daily checks including checks on incoming sludge - All system runs by gravity (from inlet) so limited operator interaction
COSTS	**CAPEX**	4	- \$204,530 for Phase 1 including design - \$3,400 per m^3 treated
	OPEX	1	- OPEX approx. \$10,800/year for FSM site labour. Desludging and transportation costs not included or \$0.50 per m^3 treated - All system runs by gravity (from inlet) so limited OPEX
	The whole life costs (WLC)	4	- Assume a plant life of 10 years, assume 5% of materials need to be totally replaced once in that period (i.e. limited replacement of as materials as a majority are long life or excavation) - \$322,760

Good 1 ◂ ● ● ● ▸ 5 Bad

Table 16:
Advantages and disadvantages of Anaerobic Lagoons

Aeration Plant

DESCRIPTION

A NGO have set up a piolet aeration FSM plant in camp 18. The FSM plant has a capacity of 20m³/d but was operating at 10m³/d during the site visit. The FSM PFD and layout are shown in Figure 34 and Figure 35.

The main process units are two Oxfam T45 tanks[16] for aeration and settlement (in series). The site is a piolet to test if an aeration treatment system is feasible in a humanitarian response.

Sludge is manually delivered to site in 50 litre drums and is emptied through 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 microorganisms to treat the FS. The retention time in the aeration tank is approximate 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 on an adjacent site. It should be noted that the aeration plant needs additional sludge handling and treatment (as with conventional wastewater treatment).

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

(16) 45m³ 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 - Aeration Plant

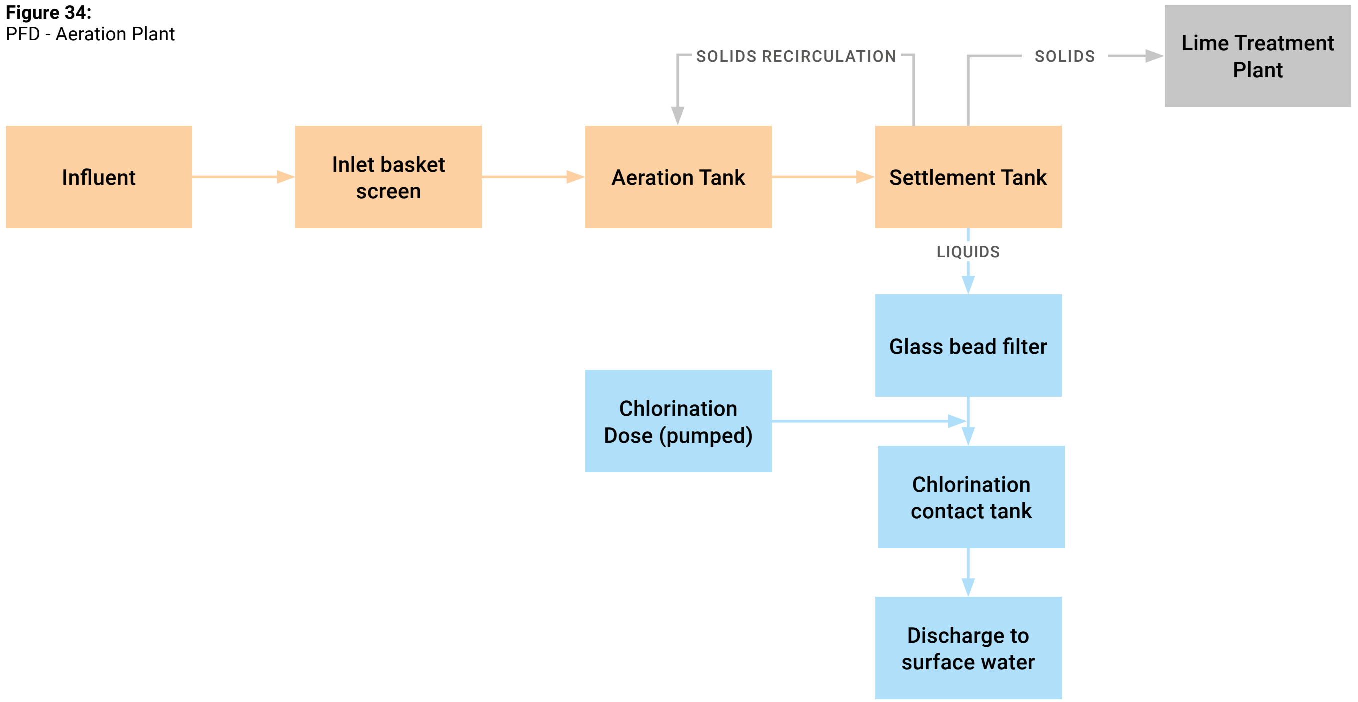
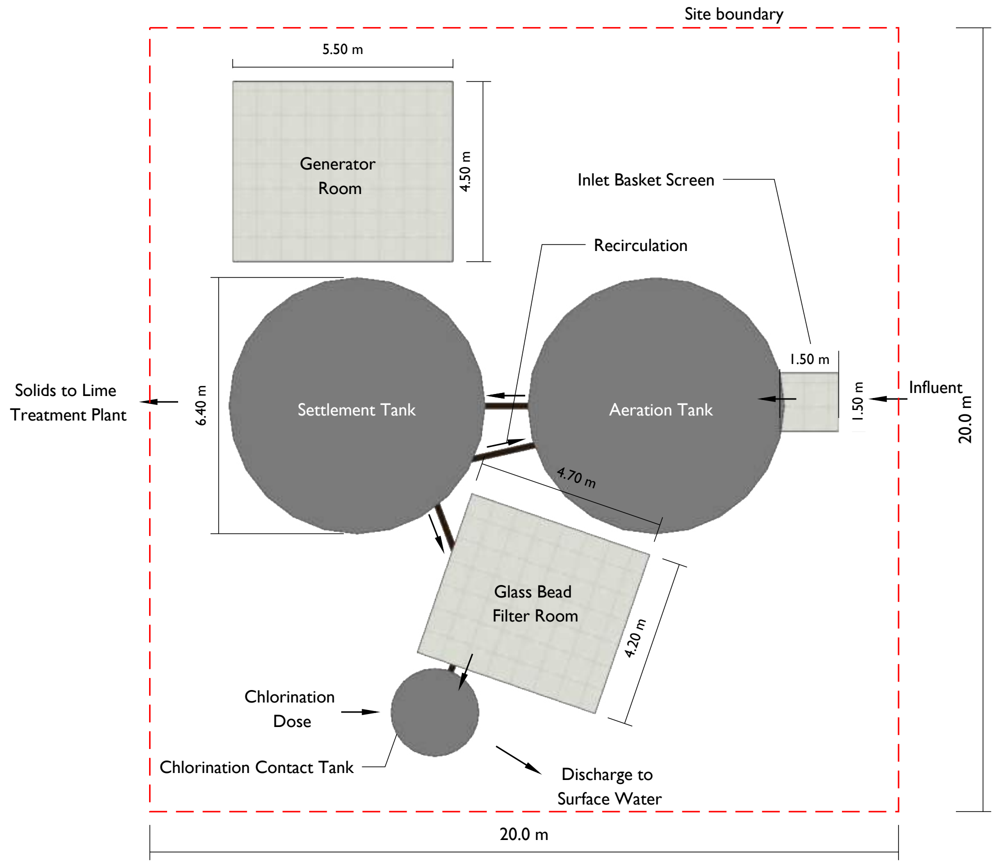


Figure 35:
Site layout plan - Aeration Plant



CENTRALISED BIOLOGICAL TREATMENT: **AERATION PLANT**

PHOTOS

Image 50:
Aeration Tank

Image 51:
Settlement tank

Image 52:
Glass bead filter

Image 53:
Chlorine dosing

CENTRALISED BIOLOGICAL TREATMENT: **AERATION PLANT**

ADVANTAGES AND DISADVANTAGES AGAINST KEY CRITERIA

CRITERIA		SCORE	FINDINGS
SITE SPECIFICS	**Capacity**		- 20m³/d. Currently treating 10m³/d
	Scale/scalability	2	- 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
	Footprint area and access	2	- Additional tanks can be added in parallel
	Speed of construction and set up	2	- All treatment units are prefabricated tanks so quick to deploy (2 weeks to set up) - Commissioning takes time (30days?) to introduce sludge and get process (microorganisms) functioning
	Resilience to disaster	3	- Prefabricated tanks might be susceptible to earthquake but quick to repair - Top of tank level could be raised if site is liable to flooding
TREATMENT PROCESS	**Complexity of treatment process**	5	- Relatively complex. Microorganisms are sensitive to influent sludge characteristics, oxygen supply, retention time etc. - If a "bad batch" of sludge can take process 30+ days to recover - Process needs monitoring and process adjustment
	Treatment effectiveness	1	- Initial results show the plant is meeting DoE standards for nutrients and solids - Site is not meeting coliform standards however is achieving helminth standards (for DOE or public health) - The liquid portion has a final disinfection step which ensure 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 prior discharge - Excess solids are taken to a lime treatment plant (i.e. require further treatment to stabilise and achieve pathogen kill)
OPERATION AND MAINTENANCE	**O and M Skills requirements**	5	- Skilled operators required, 1 or 2 can operate the site (not including desludging) - Daily tasks include backwashing of glass bead filter, discharging effluent from settlement tank to allow space for incoming flow, checks on chlorine dosing, generator etc. - Annual maintenance of mechanical equipment
COSTS	**CAPEX**	2	- CAPEX is approximately $27,300 or $1,365 per m³ treated
	OPEX	2	- OPEX approximately $10,000/year for labour, generator fuel and chlorine, plus an allowance for annual servicing. - $1.37 per m³ treated
	The whole life costs (WLC)	3	- Assume a plant life of 10 years, assume 90% of materials need to be totally replaced once in that period (i.e. Oxfam tanks, pipework etc) - $152,000

Good ◀ 1 ● ● ● 5 ▶ Bad

Table 17:
Advantages and disadvantages of Aeration plant

7 CONCLUSIONS

TECHNOLOGY

Designers and planners should consider site specific factors to select the most appropriate FSM technology. The designer should weight the indicators that are most important for the site e.g. footprint area, and use the information provided in section 4 and 5 for (summary of technologies and comparison) and Multi Criteria Assessment tool in Appendix F, to guide them to the most appropriate technology. The disadvantage 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.

It is considered that in the immediate phase of an emergency Lime treatment is still the appropriate FSM technology choice due to its speed of set up, 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 and therefore would be appropriate to use in the short term i.e. quick to constructed, limited amount of materials needed and quick to return site to former condition.

For longer term decentralised FSM technology, the Upflow Filters score well against a number of the key indicators and are therefore considered a good 'all round' 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 lowest WLC FSM plant 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 less resistant materials should be considered when assessing the WLC i.e. bamboo 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 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 lifetime and see how costs change.

FULL TREATMENT TRAIN

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

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 a 1.5m above GWL is taken as the minimum distance 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 12 months (or adequate time to achieve pathogen die off) or a final disposal location provided for burial.

General View CXB camp, surface water pond

APPENDICIES

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: lat, long, altitude)
	FSM identification number
	Phase of emergency
	PFD
	Area
	Topography
	Access & land tenure
	Typical site requirements (proximity to SW & GW, utilities etc)
	Other
TECHNOLOGY	Type of treatment technology?
	Functional?
	Life-cycle/design life
	Scale (Inc. 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 & set up
	H&S issues (with technology)
	Resilience to disaster
	Inputs
(TREATMENT) PROCESS	Objective
	Treatment mechanism (mechanical, biological or chemical)
	Complexity of process (primary, secondary, tertiary)
	Robustness/stability
	Process pinch point
	Treatment effectiveness – compliance with WHO WW reuse standards, CXB FSM strategy, removal efficiency (BOD, COD, pathogens)
	Speed of commissioning
O&M	What
	Workforce
	Skills requirements
	Frequency
	Materials and equipment
	Commissioning
	Monitoring
	Decommissioning
	H&S issues (with O&M)
	Other
COST	Capital expenditure costs (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

Table 18:
Full list of indicators assessed during study

Appendix B1
Technology comparison – Scored

		Decentralised biological and/or mechanical treatment				Decentralised biological treatment				Decentralised chemical treatment					Centralised biological treatment		SCORING RATIONAL	
		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 3 tank lime system	Anaerobic Lagoons	Aeration Plant		
Site Specifics	*Area*	3	3	5	2	4	2	1	1	4	1	3	3	4	5	2	*1 is least area per m³ treated*	*5 most area per m³ treated*
	Topography	2	2	2	2	5	5	3	3	3	4	4	3	3	4	2	*1 is can be easily constructed on a variety topography (i.e. uneven site or flat site)*	*5 is needs flat site*
	Access & land tenure	2	2	2	2	2	2	3	3	3	3	3	2	2	5	4	*1 is FSM plant can operate with pedestrian access only*	*5 is Vehicle access is needed to operate FSM plant*
Technology	*Scale (Inc. typical PE to make it efficient)*	1	1	1	1	3	3	4	4	2	2	3	2	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*
	Complexity (complicated technology/lots of equipment)	3	3	2	1	2	2	4	2	2	2	2	2	2	3	5	*1 is simple with easy to o&m technology*	*5 complex technology*
	Layout and footprint area	2	2	1	2	4	4	3	4	3	3	3	2	3	4	2	*1 is flexible layout (to suit site conditions) and low footprint area (per m³ treated)*	*5 is fixed layout*
	Materials	2	2	3	3	2	2	3	3	1	1	3	1	2	3	5	*1 is uses local materials, commonly available and with local skills/ knowledge. Easy to dismantle*	*5 is Imported materials*
	Speed of construction & set up	1	1	1	2	3	3	4	3	2	2	4	2	3	5	2	*1 is Fast to construct and set up*	*5 is slow to construct and set up*
	H&S issues (with technology)	2	2	2	3	3	3	4	3	5	5	5	5	4	2	3	*1 is low/no H&S risks*	*5 is multiple H&S risks*
	Resilience to disaster	1	1	2	5	3	3	4	4	2	2	3	2	2	3	3	*1 is Resilient to flooding and earthquake (integral to the technology/layout)*	*5 is low/no resistance to flooding or earthquake*
	Inputs	1	1	1	1	3	3	1	1	3	3	3	3	3	1	5	*1 is no external input required*	*5 is multiple external inputs required i.e. power, chemicals etc.*

Table 19:
Full technology comparison scored

Table continues on the next page

		Decentralised biological and/or mechanical treatment				Decentralised biological treatment				Decentralised chemical treatment					Centralised biological treatment		SCORING RATIONAL	
		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 3 tank lime system	Anaerobic Lagoons	Aeration Plant	1	5
Treatment Process	Complexity	1	3	3	1	3	3	4	3	2	2	2	2	1	3	5	1 is simple with low number of treatment processes	5 is complex with multiple processes including biological
	Robustness/ stability	3	3	3	2	3	3	4	2	1	1	1	1	1	4	5	1 is robust, resistant to changes in influent, operation and climate	5 is sensitive to changes in influent, operation and climate
	Treatment effectiveness	3	3	2	5	2	3	3	3	3	4	3	2	3	2	1	1 is "Good" under CXB FSM strategy & meets DoE and WHO standards	5 is "unacceptable" under CXB FSM Strategy and does not meet DoE or WHO standards
	Speed of commissioning	3	3	3	1	4	4	4	2	1	1	1	1	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 deficiency
O and M	Workforce	2	2	2	3	2	2	3	1	3	3	3	3	1	3	5	-	-
	Skills requirements	2	2	2	3	1	1	3	1	3	3	3	3	2	3	5	1 is a low level of skills (i.e. general sanitation skills) required to operate FSM plant	5 is a highly skilled operation/ technology specific i.e. above general skills
	Frequency	2	2	2	3	2	2	3	1	4	4	3	4	2	4	4	1 is low frequency of O&M needed	5 high level of O&M needed i.e. daily
	Materials and equipment	2	2	2	3	2	2	3	3	2	2	2	2	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
	Commissioning	3	3	3	2	3	3	3	2	2	2	1	2	1	3	5	1 is fast and simple commissioning i.e. "plug in and play"	5 is complicated commissioning with multiple processes to commission
	Decommissioning	2	2	1	1	4	4	4	5	3	3	4	3	4	5	2	1 is fast and easy to decommission and remove equipment i.e. clear the site and reuse equipment elsewhere (rapid deploy/remove)	5 is "permanent structures" difficult to remove and residual waste to dispose of offsite e.g. solids, contaminated media etc.
	H&S issues (with O&M)	2	2	1	3	2	3	3	3	5	5	5	5	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
Cost	Capital expenditure costs (CAPEX)	5	5	4	1	4	3	2	1	2	2	3	3	3	4	2	1 is lowest CAPEX per m^3 treated	5 is highest CAPEX per m^3 treated
	Operational expenditure (OPEX)	1	1	1	3	3	1	1	1	4	4	5	4	4	1	3	1 is lowest OPEX ($ per m^3 treated)	5 is highest OPEX ($ per m^3 treated)
	The whole life costs (WLC) of each technology	2	2	1	3	2	1	1	1	4	5	5	4	3	4	3	1 is lowest WLC over 10 years ($)	5 is highest WLC over 10 years ($)
Environmental and social context	Insights on understanding final discharge routes (environmental contamination)	2	2	1	5	3	4	4	4	2	4	3	2	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 included?	5 is poor allowance and difficult management of final products/ wastes
	Nuisance (vectors)	4	4	2	4	2	3	2	2	2	1	1	1	1	2	1	1 is not obvious nuisance/vectors (within FSM plant control)	5 is nuisance/vectors present or potentially so
	Social acceptance	3	3	2	4	2	2	2	1	3	2	2	3	1	3	3	1 is contained with limited impact on social surrounding	5 is obvious public nuisance issues 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-s5c0893e70d346829

An online multicriteria tool, developed as part of this project, can be accessed here:
https://arup.sharefile.com/d-sc838486f46a42ecb

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	CXB Septic Tank (average)	CXB Influent (combined) (average)	
pH		6.5 – 9.5	7	6.5 – 12.5	7	9	*In range*
BOD_5	mg/l	150 – 300	201	840 – 2,600	385	1,712	*In range, low for septic tank (but CXB are holding tank not sceptic tank)*
COD	mg/l	20-50,000	527	<10,000	1,183	6,414	*COD low (Note - IFRC found it high from tests at aeration site)*
COD:BOD	ratio	2:1 to 5:1	3:1	5:1 to 10:1	3:1	3:1	*In range, low for septic tank (but CXB are holding tank not sceptic tank)*
Total Solids (TS)	mg/l	30,000 – 50,000	15,490	12,000 – 35,000	5,014	15,292	*Low but ok on ave. Collection tanks may get some settlement.*
TS	%	≥3.5%	2	<3%	1	1.46	*In range*
Total Dissolved Solids (TDS)	mg/l	200 - 5000	3,758		6,481	4,594	*In range*
Total Volatile Solids (TVS)	% of TS	65 – 68%	68	45 - 75	50	57	*In range*
Suspended Solids (SS)	mg/l	>30,000	353	>7,000		353	*Low*
NH_4-N	mg/l	2,000 – 4,000	695	150 - 1000	710	881	*In range (low?)*
E.coli	cfu/ml	1 x 105	6.25E+05	1 x 105	194	7.43E+05	*High (ignore septic tank result)*
Nematode/ Helminth Eggs	No./l	20 to 60,000	967	4,000	No data	967	*Low*
Volume	l/h/d	0.15-0.2 l/h/d	0.4	2	0.4	0.4	*High but limited data. Include wastewater from washing in the latrine?*

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

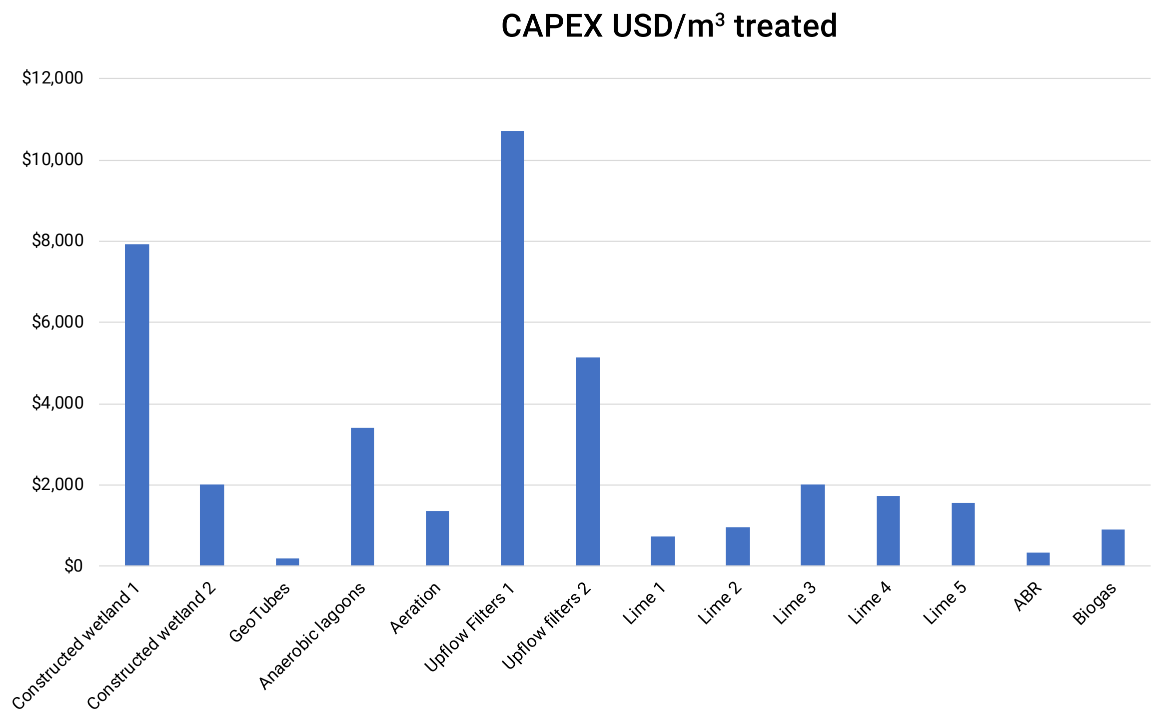
Table 20:
FS Influent Characteristics

Appendix C2
Effluent Quality

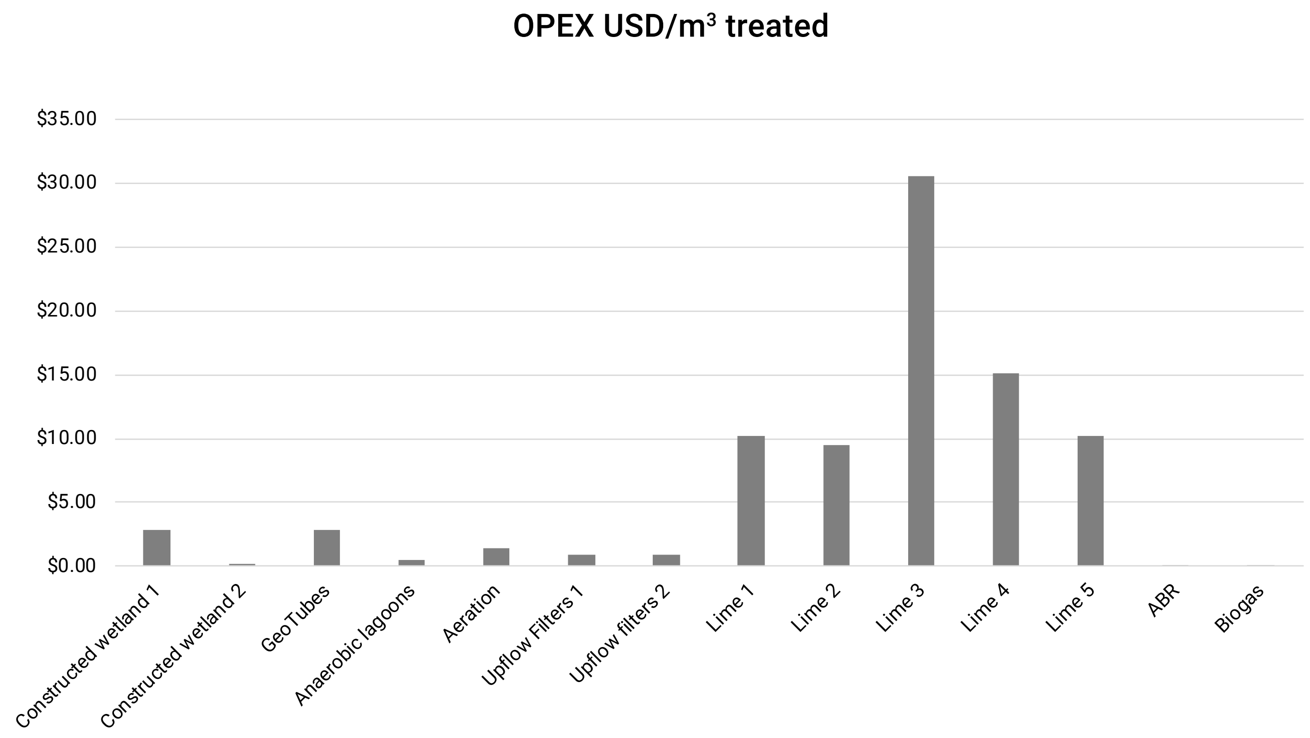
Parameter	Units	#1 Biogas Plant with Lime Treatment [FS ID: BGP C-18]	#2 Anaerobic Baffled Reactor with Drying and Filter Bed [FS ID: STF E3]	#3 ABR with Drying and Filter Bed [FS ID: ACF - EE06] #4 Open Disposal Pit (Waste Stabilization Pond) [FS ID: ACF - EE10]	#5 Anaerobic Reactor with Horizontal Filter and Discharge into Channel	#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 Aeration Plant [FS ID: IFRC ATP]
Liquid meets DoE standard?										
pH		YES	YES	NO	YES	YES	YES	NO	NO	YES
BOD_5	mg/L	NO	NO	NO	NO	YES	NO	NO	NO	0
Total Nitrogen	mg/L	YES	NO	YES	NO	NO	NO	NO	NO	0
Nitrate	mg/L	YES	YES	YES	YES	YES	YES	YES	YES	YES
Phosphate	mg/L	YES	YES	YES	YES	YES	YES	NO	NO	YES
Suspended Solids (SS)	mg/L	YES	YES	YES	YES	YES	YES	NO	YES	YES
Temperature	C	YES	YES	YES	YES	YES	YES	YES	YES	YES
Coliform	CFU/100 mL	YES	YES	NO	YES	NO	NO	YES	YES	NO
Oil and grease	mg/L	0	0	0	0	0	0	0	0	0
COD	mg/L	NO	NO	NO	NO	YES	NO	NO	NO	NO
Liquid meets protection of public health (WHO) standard?										
Helminth eggs in effluent	No./L	10,000	0	10,000	200	0	100	100	0	0.6
Coliforms in effluent	CFU/100 mL	300	0	25,000	300,000	4,500,000	13,000	0	0	150,000.0
Coliform reduction	CFU/100 mL	2,799,700	3,000	45,000	-1,700,000	-2,500,000	1,960,000	180,000	1,500,000	850,000.0
Coliform	CFU/100 mL	YES	YES	NO	YES	NO	NO	YES	YES	NO
Helminth (Ascaris lumbricoidis)	no./L	NO	NO	NO	NO	YES	NO	NO	YES	YES
Solids meets protection of public health (WHO) standard?										
Coliform	CFU/100 mL	NO	YES	NO	YES	NO	NO	YES	YES	YES
Helminth (Ascaris lumbricoidis)	no./L	NO	NO	NO	NO	NO	NO	NO	YES	NO

Table 21:
FS Effluent Charaterisitics

Appendix D
CAPEX and OPEX details



CAPEX/m³ treated

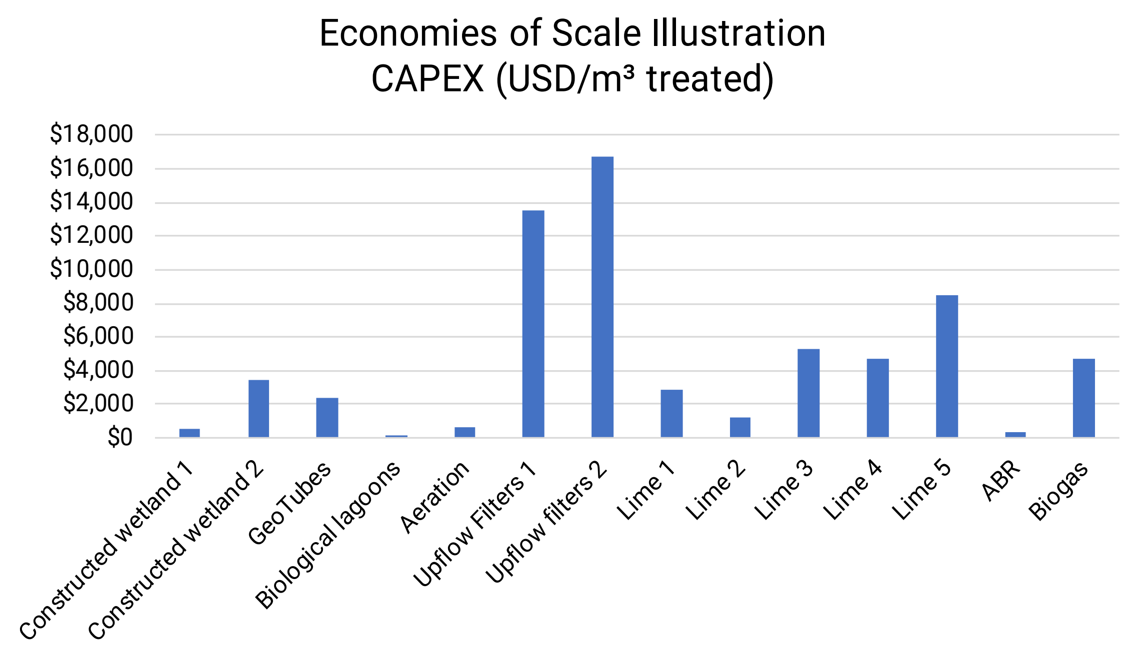


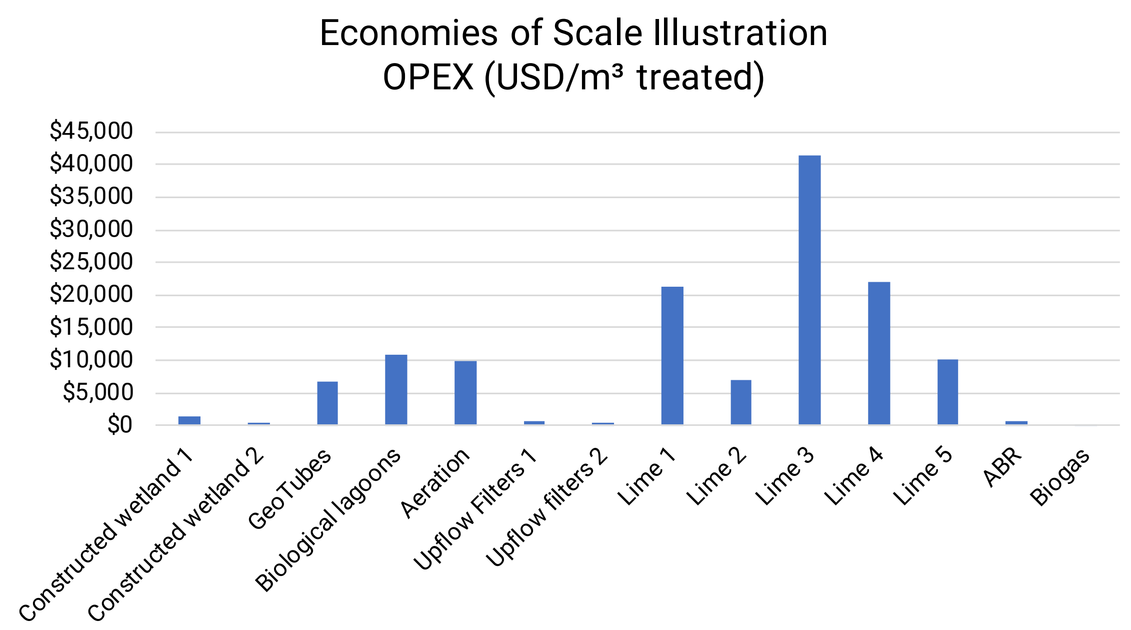
OPEX per year

Appendix E
Centralised / Discentralised - Economies of Scale

One Anaerobic Lagoon with a capacity of 60m³/day versus multiple decentralised plants

Site	Treatment capacity (m³/d)	Number of plants required for a capacity of 60m³/d	CAPEX USD	CAPEX (USD/m³ treated)	OPEX (USD/year)	OPEX (USD/m³ treated)	WLC (USD)
Constructed wetland 1	1.43	42.00	$33,480	$558	$62,093	$1,478	$684,540
Constructed wetland 2	5.00	12.00	$17,280	$3,456	$4,493	$374	$79,488
GeoTubes	6.50	9.23	$15,785	$2,428	$61,676	$6,682	$664,117
Biological lagoons	60.00	1.00	$11,340	$189	$10,800	$10,800	$119,907
Aeration	20.00	3.00	$12,420	$621	$30,043	$10,014	$324,025
Upflow Filters 1	2.00	30.00	$27,000	$13,500	$19,008	$634	$241,380
Upflow filters 2	1.75	34.29	$29,314	$16,751	$19,749	$576	$250,251
Lime 1	5.71	10.50	$16,470	$2,882	$224,154	$21,348	$2,271,186
Lime 2	11.00	5.45	$13,745	$1,250	$37,973	$6,962	$401,724
Lime 3	3.70	16.22	$19,557	$5,286	$669,250	$41,270	$6,714,010
Lime 4	4.00	15.00	$18,900	$4,725	$331,776	$22,118	$3,365,010
Lime 5	2.70	22.22	$22,800	$8,444	$224,320	$10,094	$2,268,280
ABR	35.00	1.71	$11,726	$335	$1,370	$799	$26,599
Biogas	4.00	15.00	$18,900	$4,725	$1,255	$84	$39,005





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