SMALL-SCALE WASTEWATER TREATMENT TECHNOLOGIES FOR CHALLENGING ENVIRONMENTS

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ABSTRACT

One in every three people globally still lack access to appropriate sanitation, those without sanitation are increasingly those who reside in remote, temporary, or challenging environments. In order to achieve full coverage by 2030 will require a significant shift in technology development and marketing (UN, 2016). Recognising this, the Engineers Without Borders (EWB) Sanitation in Challenging Environments (SCE) Project takes a sector-wide collaborative approach to improve awareness, funding, technology options and action on SCE in Cambodia. Challenging environments defined as rural locations where it is either difficult to construct conventional pit latrines or where they would risk contamination of the environment, particularly groundwater and surface-water resources.

Through collaborative partnerships EWB has been working to expand, test and monitor sanitation technology options available in challenging environments. This paper examines three technologies adapted to challenging environments that demonstrate innovative and novel approaches to a largely under-resourced issue, these include:

i. ATEC* Biodigester – a combined environmental sanitation and energy production technology. The biodigester treats household toilet waste, provides renewable bio-gas for cooking, and produces nutrient rich fertiliser. The ATEC* biodigester is uniquely suited to flood prone and high groundwater environments.

ii. The 3C pit – a simple, cost effective adaption to the widely used pit-latrine for areas of high-groundwater and minor flooding. The design uses three chambers to improve effluent treatment compared to a standard pit-latrine before the effluent leaches into surrounding soil.

iii. HandyPod by Wetlands Work! – a unique sanitation technology using local materials for floating communities who have no alternative but to defecate into the water-body they live on.

Early results indicate a two to three log-order reduction in pathogen levels before effluent enters the surrounding environment. This is a significant improvement on existing latrine technologies for these environments. To reach all affected communities, will require continued investment in research and development, manufacturing, supply chain enhancement, demand creation and marketing.

KEYWORDS

Challenging, Flooding, Sanitation, Technology, WASH, Wastewater Treatment

1 INTRODUCTION

In 2016 the United Nations released the Global Sustainable Development Goals; specifically Goal 6 aims to ensure access to adequate and equitable water and sanitation for all by 2030, including an end to open defecation (UN, 2016). In context, 2.4 billion people globally still lack access to basic sanitation services and more than 80% of wastewater resulting from human activities is discharged into rivers or sea without any pollution removal (UN, 2016). To achieve these targets, there is an urgent need for focused efforts, new ways of thinking, and innovative solutions.

To reach the remaining human population who lack sanitation services, a significant shift is required in how sanitation solutions are developed and marketed. Increasingly those without access are vulnerable communities who have little or no access to finance, live in temporary structures or migrate in search of work (OECD, 2002). In many countries with high population density combined with no social security or poor land planning people end up living on the edge of rivers, beaches, swamps, on reclaimed land, or in extreme circumstances living in boats or floating homes. These conditions present social, political and engineering challenges. Achieving 100% sanitation coverage requires new solutions and approaches to reach those who live in these extremes.

A *Challenging Environment* in EWBs work, refers to a rural location where it is either difficult to construct conventional pit latrines or where the use of conventional pit latrines would risk contamination of the environment, particularly groundwater and surface water resources. This paper focuses on the case study of Cambodia, where the most common challenging environments are flood affected, high groundwater, floating communities and seasonally water-scarce areas (WSP, 2011). Many parts of Asia and the Pacific also experience these environments, including areas of Indonesia, Vietnam, Bangladesh, and Pacific Islands. There is a need to have customised designs and approaches that enable safe, affordable and appropriate access for all people to access sanitation

Cambodia has a national target of reaching 100% sanitation coverage by 2025, up from the current level of 52% (Cambodia National Institute of Statistics, 2015). With over 25% of the population (at least 4 million people) estimated to be affected by challenging environments (WSP, 2011).

Cambodia has been the focus of efforts by Engineers Without Borders since 2009, when engineers embedded in partner organisations started to recognise a gap in sanitation solutions offered for communities in challenging environments. In 2014, EWB established the Sanitation in Challenging Environments (SCE) Project in Cambodia, taking a sector wide (collective impact) approach to improve knowledge and action on sanitation for communities affected by their challenging environment.
The SCE Project takes a multi-faceted approach to its program of work focusing on three key elements:

- Collective Impact: Facilitating in-depth sector-wide discussion about SCE. Bringing focus to the challenge of SCE and initiating dialogue and information sharing between international and local organisations and government about SCE.
- Technology designs & trials: Developing and trialling new and innovative small-scale wastewater treatment technologies for households and communities in partnership with local organisations.
- Education, research & behaviour change: Development of educational resources and training for NGO's and communities on Challenging Environments. Research into SCE through Australian institutions, and development of behaviour change resources & approaches specific to challenging environments.

With increased focus and awareness the results include improved local standards; specific government targets; increased technical innovations; and additional funding.

This paper examines three technologies (ATEC* Biodigester, 3C Pit Latrine and HandyPod) developed for challenging environments by EWB in partnership with Live & Learn, iDE and Wetlands Work! respectively. These technologies demonstrate innovative and novel approaches to a largely under-resourced issue. These technologies also highlight the importance of collaborative partnerships and targeted funding support when attempting to address an issue which is complex, under-resourced and largely overlooked.

2 SANITATION IN CHALLENGING ENVIRONMENTS

2.1 TRADITIONAL APPROACHES

Traditional approaches to sanitation in rural Cambodia have relied on effluent seepage into soil for treatment and disposal. Non-Government Organisations (NGOs) and government have used Community Led Total Sanitation (CLTS) and introduction of Sanitation Ladder (start simple and upgrade toilets with time) to trigger households to move from open defecation to installed toilet systems.

In recent years organisations in Cambodia have established standardised low cost sanitation systems, such as the Easy Latrine. In 2009 the Easy Latrine designed by International Development Enterprises (iDE), with partners WaterSHED, and built by local masons, was the first packaged latrine product in Cambodia. The Easy Latrine consists of 3 concrete rings, pipe connectors and a squat pan for US$50, a price point achieved through substantial strengthening of supply chains and rationalisation of designs (Business Fights Poverty, 2014). Householders then choose the location, and design of their shelter system depending on their budget. These toilet systems have become immensely successful in Cambodia (and other countries) due to their simple and affordable nature.

Seepage systems work fine in well-draining soil, away from groundwater or river systems or seasonal flooding situations. However, areas that are subject to unusual conditions (e.g. poor soil porosity, flood affected, high groundwater) suffer from overflowing, poor retention time, sludge accumulation or contamination of local ground or surface water bodies. Systems are also often not constructed to withstand flooding, making them unusable and prone to damage during the wet season. Areas with high groundwater and areas prone to flooding present the greatest risks to ground and surface water contamination because well sealed pits and vertical separation is required between the base of latrine pits and the saturated zone to prevent pathogen contamination (Graham and Polizzotto, 2013). Traditional technologies and demand creation approaches for sanitation in communities faced with challenging environments have contributed to the degradation of water resources and reversed some of the benefits of sanitation.

2.2 CHALLENGING ENVIRONMENT TYPES

2.2.1 Flood - Affected

In Cambodia over two and a half million people live in areas that are seasonally flood affected, ranging from short term low levels to elevated water levels for extended periods (refer to Figure 1 showing a typical house) (WSP, 2011). Latrines constructed with conventional materials such as concrete rings and pits are possible in some locations, however construction quality is a significant issue with intermittent flooding weakening structures and leading to both super and sub-structure collapse (WSP, 2011). During floods, households are known to open the top of their pits during flooding to 'clean' the pit, washing the faecal waste and sludge into the surrounding waters (WSP, 2011).

Figure 1: A typical house in Prek Chrey, elevated on stilts to be above flood height

2.2.2 High Groundwater

High groundwater conditions pose many challenges for safe water and sanitation planning. Especially for communities who rely on water sourced from groundwater sources or rivers/springs fed by groundwater can be contaminated by seepage based toilet systems. In rural and peri-urban areas of Cambodia, groundwater level is seasonal, and in the wet season can be as close as 20cm to the surface, in these conditions elevated and sealed systems are essential for preventing contamination.

2.2.3 Floating

In Cambodia, the Tonle Sap Lake is home to an estimated 100,000 people living in floating communities (refer to Figure 2) (WSP 2011). Other floating communities worldwide exist in the Mekong Delta of Vietnam, Makoko Nigeria, Inle Lake Myanmar and others. The Tonle Sap Lake is unique in that water levels can vary 10 metres throughout the year. Meaning not all households are afloat year-round. During the dry-season some houses come to rest on exposed banks, beside 'forest islands', or on the banks of tributaries when water levels decrease (WaterAid, 2017). Householders either defecate directly from their house or travel by boat to small islands, the waste then enters the water where they swim, wash and collect water for domestic use (McGill, 2013).

Figure 2: Tonle Sap Floating Houses

Traditional CLTS approaches used on land are also ineffective in floating communities, where village transect walks, and identification of commonly used open defecation sites are not possible. Adapted CLTS approaches for floating communities are being trialled by EWB partner organisations RainWater Cambodia and Wetlands Work!, for example, use dye to depict the movement of faeces in a large tub of water (Chakraborty, 2017). Alternative marketing methods using raffles (prizes of toilet systems and hygiene products) combined with community gatherings and school-based education has been used as an effective tool for demand creation for floating communities (WaterAid, 2017).

2.3 BARRIERS TO OVERCOME

Little progress has been made to develop and disseminate appropriate sanitation solutions for sanitation in challenging environments worldwide due to the complexity of the problem and numerous barriers to overcome. These barriers include:

Cost – communities who live in challenging environments are relatively poor whilst appropriate sanitation solutions are significantly more expensive (materials, transport and sludge disposal), with limited technical options available, and non-existent supply chains (WSP 2011).

Expectations – subsidised and free toilets have raised expectations for latrines, and families will delay purchasing toilets until they can afford 'luxury ones' with brick or concrete shelters and tiled floors, according to Chreay Pom, Director of the Cambodia Department of Rural Health Care (DW, 2015).

Migration – water quality and quantity are among the major actors forming the rural push from the Tonle Sap Lake Region, with changes in the water flow and water quality having strong effects on the lives of over 1 million Cambodian rural people (Heinonen, 2006). Migration can be permanent or temporary, with many workers migrating leaving vulnerable family members, often children and elderly at home. Migration affects people's willingness or ability to invest in a toilet.

Maintenance – elevated structures require improved construction quality, greater monitoring and maintenance. The need to seal a system to prevent leaching into groundwater or floodwaters creates a barrier to waste removal, which becomes a significant challenge in these areas due to difficult access. Faecal sludge management (FSM) even in normal environments is still very poorly managed or understood. A review in Cambodia commissioned by World Bank Water and Sanitation Program (WSP) found FSM is not covered by national policy and there are no targets, strategies or political will to address the challenge (Peal and Evans 2015).

Social-Cultural-Political – communities in challenging environments often face difficult social circumstances, for example many residents of Tonle Sap Lake are stateless Vietnamese without rights to land, citizenship status, and limited Khmer language skills they are often excluded from subsidies and passed over in health and sanitation services (Villadiego, 2017).

3 TECHNOLOGY INNOVATIONS

3.1 ATEC* BIODIGESTER

ATEC* is a social enterprise that has developed the first mass-produced stand-alone biodigester that can be installed in high groundwater; earthquake and flood affected areas (refer to Figure 3) (ATEC, 2017). Biodigesters are anaerobic tanks that break down organic waste, such as cow manure or human faeces, using methanogenic bacteria to produce both biogas which can be used for household cooking and nutrient rich fertilising slurry (Vögeli et al., 2014). The ATEC* Biodigester can be placed in locations that experience severe seasonal flooding over 1.4m in height. The ATEC* Biodigester has evolved from numerous years of background research and testing by EWB, together with Live and Learn Environmental Education, on the performance and functionality of biodigesters for challenging environments (McGill, 2013).

3.1.1 DESIGN

Standard biodigesters in Cambodia are constructed out of bricks and mortar and buried partially below ground level, meaning they are not suitable to flood-prone areas as they are easily inundated. Brick and mortar systems are also susceptible to cracking in areas with high groundwater or unstable soils. The ATEC Biodigester is a manufactured solution which addresses these issues; the initial design has been developed for animal manure, with toilet connections now being trialled.

Technical Specifications of ATEC* Biodigester:

- Dimensions: 2070mm (H) by 1,500mm (Dia)
- Weight: 70 kg (empty)
- Capacity: 3650 L (3.65m3)
- Material: Export quality UV treated linear low-density polyethylene
- Inputs: Animal manure (cow, pig, chicken), human waste, kitchen waste, green waste
- Daily feed input range: 20-80L
- Daily gas output range: 760L-1400L (manure)
- Daily fertiliser output: 20-80L
- Retention time: 30-120 days - for systems with toilet connection a minimum retention time of 60 days is recommended to appropriately treat the human waste. This means a maximum daily manure-slurry input of 30L

Figure 3: Computer model of the ATEC Biodigester*

3.1.2 HOUSEHOLD TOILET CONNECTION TRIAL

Together with ATEC* and local community partner Khmer Community Development (KCD), EWB has been trailing the pre-fabricated ATEC* Biodigester as a combined environmental sanitation and energy production technology for severely flood affected communities in Cambodia. The biodigester treats the household toilet waste, provides renewable energy in the form of bio-gas for cooking, and produces nutrient rich fertiliser that is easy to handle. The anaerobic processes inside the bio-digester include high levels of methanogenic bacteria that neutralise pathogens from human waste.

The biodigester is directly plumbed to the household’s toilet and this, combined with the biodigesters ‘standard’ input of cow, buffalo or pig manure, is capable of producing enough gas to meet all of a household’s cooking needs (ATEC, 2017). Using the biodigester as a combined sanitation and energy technology addresses numerous cross-cutting issues including providing security for women and girls who will have access to a convenient and sanitary toilet; provides a smoke free cooking environment; reduce environmental impact through the elimination of wood as cooking fuel; and provides environmental sanitation through appropriate disposal of household toilet waste.

The EWB supported trial is the first time the ATEC* biodigester has been installed and tested with a toilet connection. While the ATEC* unit can be used in normal environments, it is also uniquely suited for use in flood-affected areas due to pre-fabricated, liquid-tight construction that is flood-proof for water levels more than 1.4m. In the community of Prek Chrey in southern Cambodia five units have been installed with toilet connections and are being tested for performance and pathogen removal rates (refer to Figure 4). The toilets connected as part of the trial will be elevated and directly connected to the house (refer to Figure 5).

The biodigester requires a significant financial outlay of US$650, however as well as being a sanitation technology; it also provides enough gas to meet all of a household's cooking needs. This saves the average household at least US$750 over three years, based on households without a biodigester typically costs for use of wood, charcoal, or disposable gas bottles as their fuel source for cooking.

Figure 4: The ATEC biodigester installed in a flood-prone area with toilet connection*

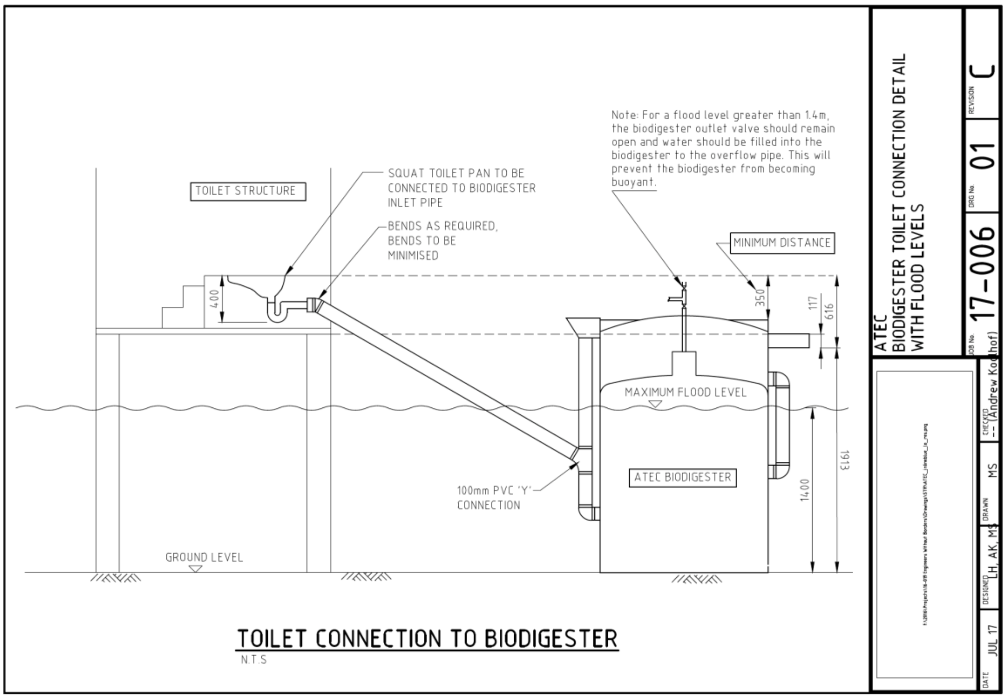


Figure 5: Drawing showing details of the ATEC Biodigester with toilet connection

3.1.3 TESTING AND RESULTS

Preliminary *E Coli* test results shown in Figure 6, for the ATEC* Biodigester with and without toilet connection, show average reduction in pathogen level of 2-log order, between input and outlet E-Coli levels. The average reduction in *E Coli* levels tested is as expected from an anaerobic biodigester.

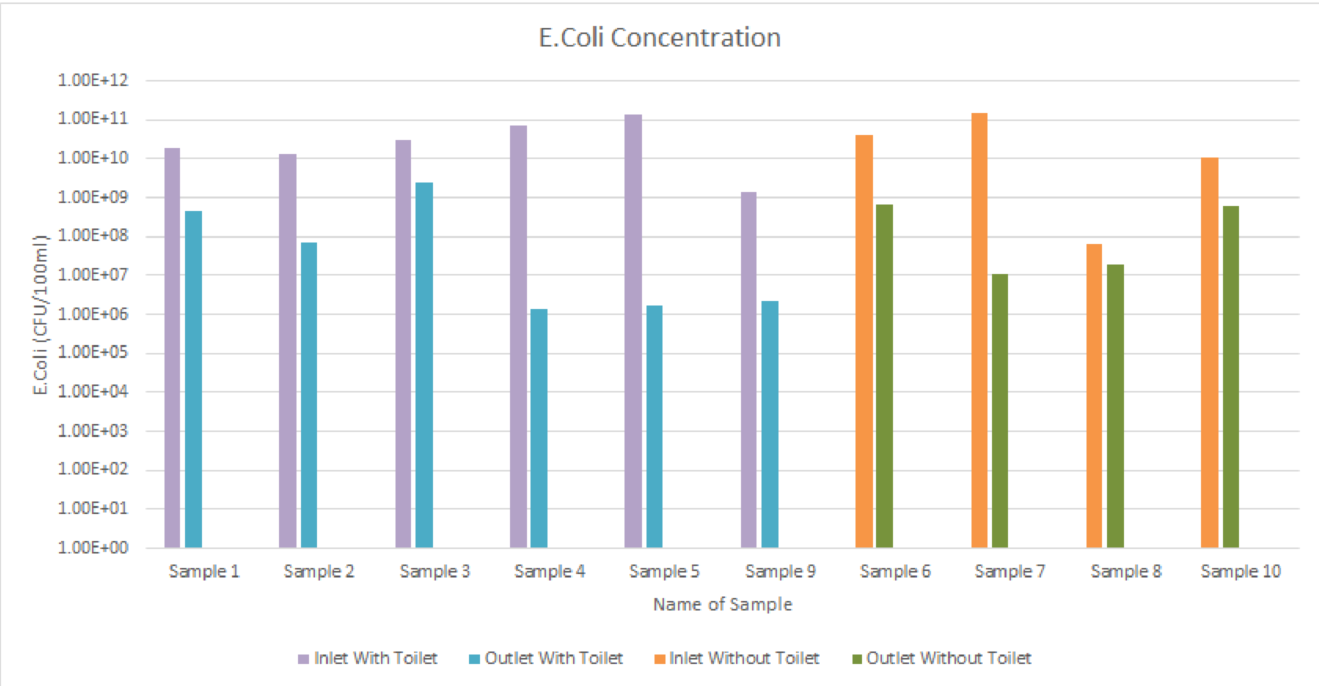


Figure 6: Inlet and outlet E.coli concentration of the biodigester with and without toilet

Testing of biodigesters with and without toilets attached, show no measurable difference in results. Compared with typical *E coli* in raw human waste and animal manure of $5x10^9$ cfu/100ml and in treated wastewater $3x10^6$ cfu/100mL (Cheremisinoff, 2002), high inlet pathogen levels in some samples raise questions about accuracy of testing conducted in Cambodia. Additional rounds of testing are ongoing to validate these results.

Key takeaways from this testing are reduction across the system is good (inlet vs outlet), even if there was a problem with the scale (magnitude) of the results collected, this offset discrepancy was present for both the inlet and outlet samples and thus it is still possible to derive findings & comparisons between the inlet and outlet E Coli levels.

Feedback from households, confirm all systems are producing enough gas for cooking requirements. With time and money saved and reduced health effects due to smoke from fire using wood for cooking. The slurry produced and used as a natural fertilizer instead of chemicals. Some issues were raised regarding human faeces floating at manure inlet point - recommend placing a 'cap' on feed point for future designs.

3.2 3C PIT LATRINE

Globally 1.77 billion people use pit latrines as their primary means of sanitation (Grahams, 2013). Conventional pit latrines coupled with pour-flush ceramic latrine pans, are by far the most widely used sanitation technology in Cambodia. Pit latrines pose significant risk to ground and surface water resources in areas of high groundwater and seasonal flooding (WSP, 2011), however there are no practical or widely known alternatives to the pit latrine for households. To address this EWB has developed the design for the 3C pit - a simple adaption to the standard pit latrine to better suit mildly flood prone and high groundwater areas.

The 3C pit is a simple adaptation to a standard concrete-ring latrine pit that improves effluent quality and reduces potential contamination of elevated water tables or areas that experience minor seasonal flooding. The 3C pit has been designed to be easily scalable and use locally available materials and construction techniques, while not costing significantly more than a standard latrine pit. The 3C pit costs US$40 more than a standard concrete-ring pit latrine. Compared to a standard latrine pit the 3C pit also elevates the effluent leach point, increasing the vertical separation between the exit point and groundwater table by 0.5m. The 3C pit, will be integrated into the new iDE sky latrine, designed for flood-affected households to be able to retrofit into their elevated houses (refer to Figure 7).

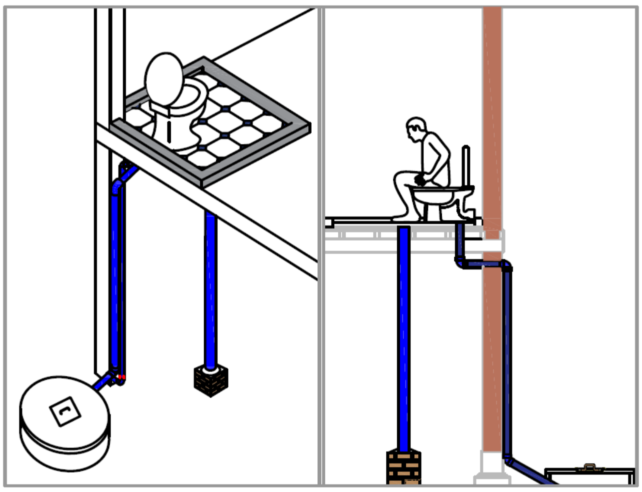


Figure 7: Sky latrine from iDE which will be built to connect to 3C Pit system

3.2.1 DESIGN

The 3C pit is a standard concrete pit latrine sealed on a concrete base and divided into three internal chambers. The three chambers are spread across the 4 quadrants of the pit (refer to Figure 8). The maintenance requirements are similar to a standard latrine pit, i.e. any blockages will need to be cleared, and the pit will need to be periodically emptied of faecal sludge, typically required once every two to four years.

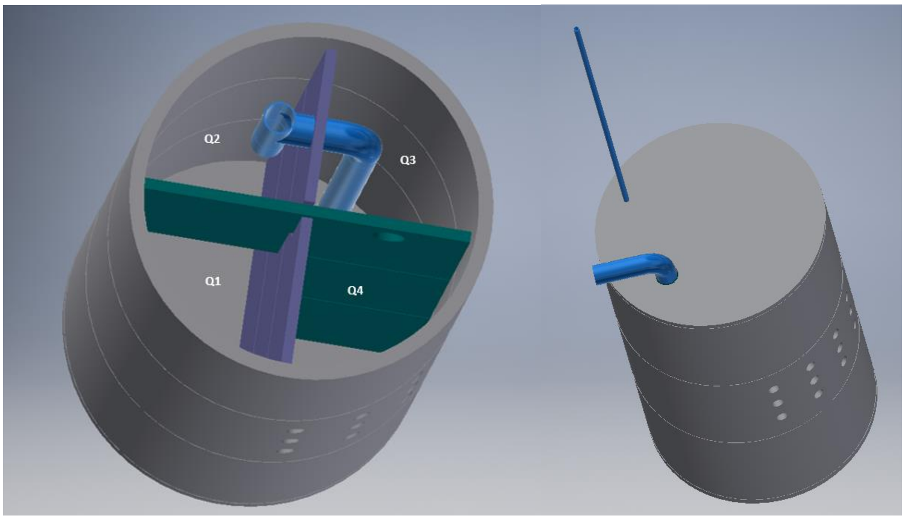


Figure 8: 3C Pit Computer Model Visualisation

The 3C pit design is based on principles similar to those of a septic tank or anaerobic baffled reactor. The 3C pit is designed to have a hydraulic retention time (HRT) of at least 10 days, and incorporates a filter chamber to encourage bacterial growth and reduce pathogen levels. A series of concrete dividers and PVC piping is used to direct flow through the pit. With multiple chambers for settling of solids, the risk of solids clogging soil pores in the surrounding leachate soil is also significantly reduced. The design uses standard 1m diameter concrete rings that are widely available in towns and markets across Cambodia. Three concrete rings are stacked vertically on top of each other and placed on a concrete base, typically a pit lid. The addition of filter material will be tested in the second chamber, Quadrant 3 (Q3). EWB and Wetlands Work! have previously conducted testing and experimentation on the effectiveness of different filter materials in pit latrines including gravel, polystyrene and coconut husk. Gravel has been selected as the filter medium due to its widespread availability and tested performance.

Shaju and Neera (2013) have shown that modified soak pits (concrete pit latrines) with multiple chambers and a filter material in the second chamber show a significant improvement in treatment efficacy compared to standard pit latrines. They found a two-chamber system with gravel as filtration material could achieve a two-log order reduction in E Coli levels between influent and exiting effluent. They also found that 'planted systems' where plant root systems are located in the immediate vicinity of the effluent exit point noticeably improved effluent quality. The 3C Pit System has been designed and is expected to have a process flow and results comparable to those recorded by Shaju & Neera (2013). The 3C pit system has also been designed to have functionality and performance similar to the *Cess-to-fit* developed by the Asian Institute of Technology (AIT) in Bangkok, which showed significant improvement on wastewater quality. Wetlands Work! have also tested a trial system that is larger in size but has similar functionality to the 3C pit. This showed a two to three log-order reduction in indicator organisms (*E Coli*) across the system (Hand et al., 2016).

The flow through the 3C pit can be unrolled into the following process flow diagram (Figure 9), described in Table 1.

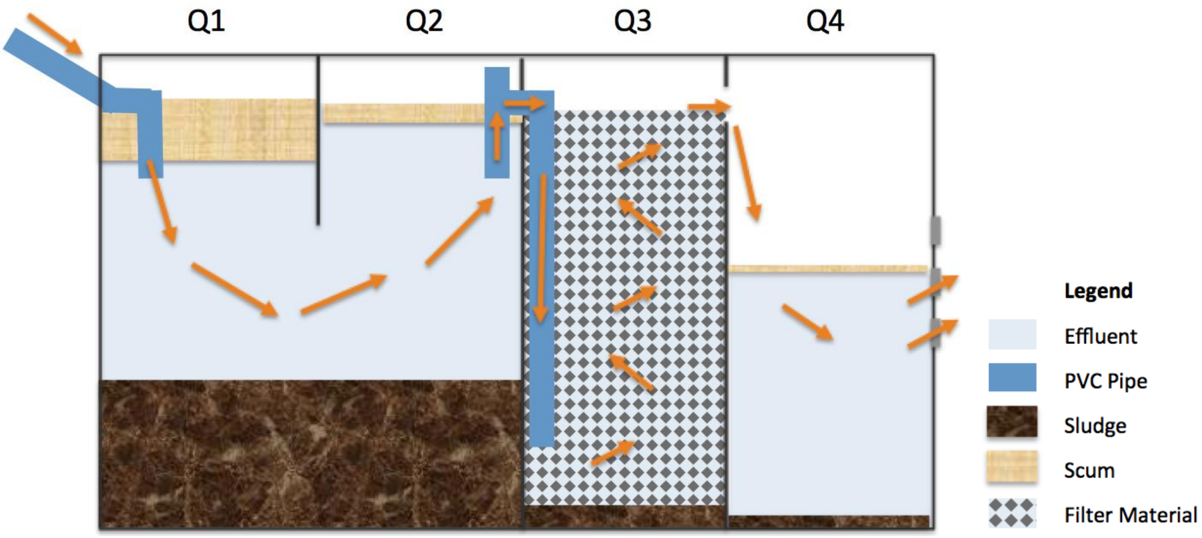


Figure 9: 3C Pit Process Flow Diagram

Table 1: Summary of layout and flow path through the 3C pit

Q1	Effluent enters the pit through the inlet pipe. The end of the inlet pipe is below the effluent level. The majority of the scum & low-density matter will accumulate here; whilst solid matter (sludge) will settle out at the bottom of Q1 & Q2.
Q2	Some scum will be pushed across to the top of this quadrant from Q1. The effluent exits Q2 into Q3 through a 90mm PVC T-Piece with a 200mm downwards extension to prevent scum from flowing into Q3.
Q3	A separate chamber filled with the filter material. The effluent enters Q3 at the base through the pipe and flows gradually upwards through the filter medium before flowing through a hole at the top in the concrete divider.
Q4	Effluent finally accumulates in the chamber where it exits out through twelve holes and infiltrates into the surrounding soil. The exit holes are located in the middle ring, halfway up the height of the pit. Gravel is placed in a 0.5m arc around the outside of these holes to assist with infiltration into the surrounding soil.

3.2.2 CONSTRUCTION AND PROTOTYPING

Two prototypes of the 3C pit have been built by EWB in December 2016 and March 2017 at a mason's yard in the south of Phnom Penh.

The 3C pit is built from the bottom up. First the concrete base is positioned in the hole and cement paste/mortar applied to the base before the first ring is placed on it (refer to Figure 10). The first layer of divider panels is then carefully positioned. The ring and divider panels are fixed in place and made watertight using a two-step process (refer to Figure 11). All joins are first sealed using cement paste (i.e. gaps filled etc.), and a 40mm fillet of mortar is placed over the top to provide structural integrity and improve the water-tightness. All joints should be sealed from both sides where possible. The remainder of the chamber is built a layer at a time, and all joints sealed with the same process.

PVC pipe components are mortared in place once the pit is assembled. It is very important to assemble the dividers carefully with a good seal between all the concrete rings and concrete dividers as well as the pipe connections throughout the system. Finally a lid is placed on top of the pit and sealed using mortar.

Figure 10: 3C Pit Bottom ring mortared onto base. Divider panels being installed/mortared

Figure 11: 3C Pit Top-Down view pit filled with water (no filtration medium added yet in Q3)

Construction of the 3C pit requires an increased level of training, skill and attention to detail compared to a standard pit latrine. Without attention to construction quality, the effectiveness of the pit in improving effluent quality and preventing ground and surface water contamination will be reduced. Mason knowledge, competency and attention to detail have been recognised by the SCE project, with training materials developed to improve toilet siting and construction techniques.

Key learnings from the construction of these rings have been used to improve the effectiveness of the design:

- Create a template/specification panel reinforcement to reduce likelihood of breakage (refer to Figure 12);
- Apply cement paste and mortar to seal all joints in the pit effectively, to ensure watertight;
- The cement paste and mortar should be applied in a fillet style;
- Inlet pipe directed downwards into Q1 and extends at least 100mm below surface level to reduce pushing force across pit;
- Extend Q2-Q3 T section down 200mm to prevent accumulated floating scum after long period of usage.

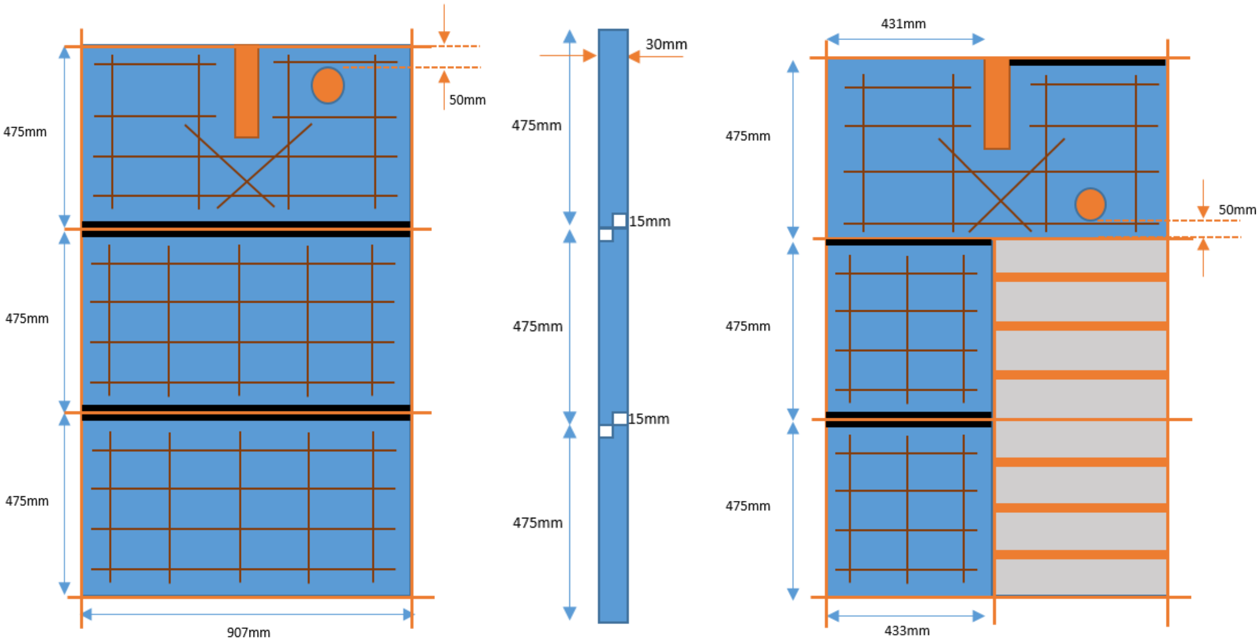


Figure 12: 3C Pit panel reinforcing (special layout to stop cracking at top of panel)

3.2.3 TRIAL

EWB has partnered with International Development Enterprises (iDE) to trial the 3C pit with households in Cambodia's Prey Veng province in second half of 2017. Ten 3C pit systems will be built at households in partnership with iDE and a selected LBO (Latrine Business Owner) in Prey Veng province. Two variations of the pit design are being constructed (five of each), with half using a filter material in Q3, and half without. Households will be interviewed prior to construction to ensure suitability as a testing site and informed of operation and maintenance requirements.

The trial has been designed to enable a full set of comparative E Coli results between the two 3C pit variations and 'standard' pit latrine. The testing methodology will use tube wells made out of perforated PVC pipe to a depth of 1.5m, and 0.5m away from the pits in gravel (refer to Figure 13). These tube-wells will be used to collect liquid samples that represent the liquid/effluent quality in the ground immediately around the latrine pits.

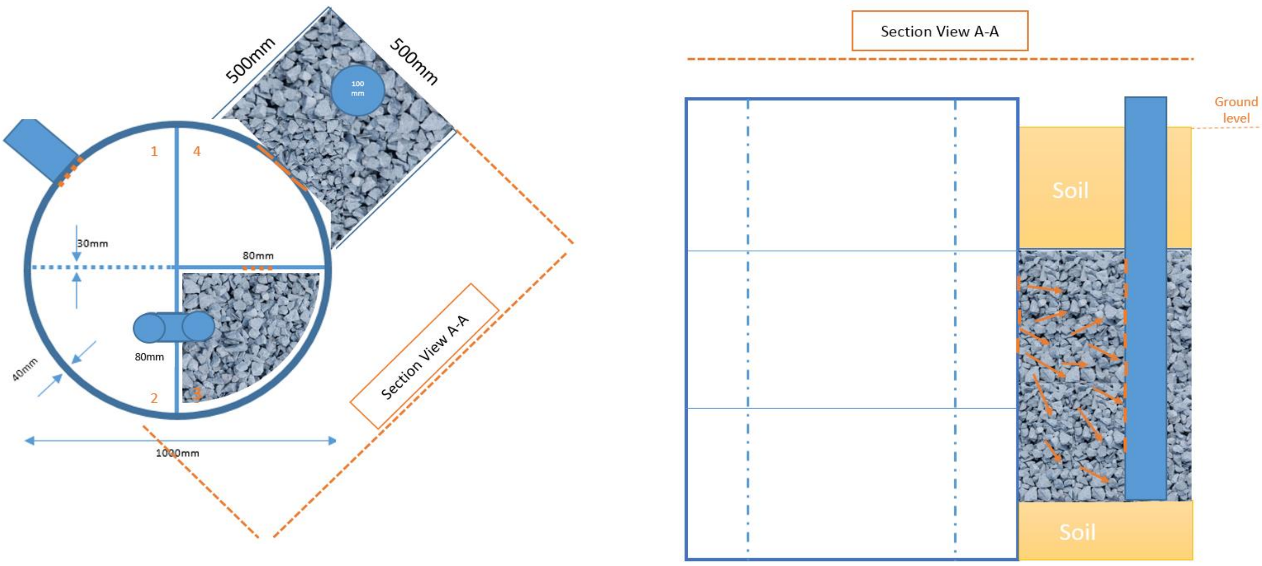


Figure 13: 3C Pit with additional 0.5x0.5m gravel pit and tube well for testing

3.3 HANDY POD BY WETLANDS WORK!

There have been few sanitation options developed for floating households and none have yet been successful in being widely accepted and adopted. Unlike other homes which are in a fixed location and either built at ground level or elevated on posts, wastewater treatment systems that need to be installed into the ground or that rely on filtration into soil cannot be used in such environments. From a marketing standpoint, the difficulty is compounded by the concept of a sanitation treatment system for houses being completely new to purchasers and users.

EWB partner, Wetlands Work!, has developed the HandyPod system, a wastewater treatment system for floating households. Through several rounds of prototype iteration the HandyPod design has undergone a range of treatment performance and usability testing. The current version of the HandyPod is being actively marketed in two communities on the Tonle Sap Lake.

3.3.1 DESIGN

The HandyPod consists of a ceramic squat latrine pan, with two digesters and a filtration unit attached to the side of the house (Wetlands Work!, 2017). The systems are manufactured from locally available components including plastic barrels, PVC pipework, timber and filtration material (refer to Figure 14 and Figure 15). The system is sized for a family of 6 people, and reduces faecal coliforms to acceptable levels for ambient contact. In larger installations (such as at schools) the filtration unit is a bio-filtration unit using hyacinth plants to further improve effluent quality before discharge. Due to record low water levels on the lake, the systems have been designed to function in amphibious conditions (both floating and land-based situations) many houses that had previously been permanently floating have become beached (WaterAid, 2017). The household system has a cost of US$150, which is a significant sum of money for the households on the lake, however with the establishment and support of local village savings group's households are now able to access appropriate loans to purchase a HandyPod system if they desire.

Figure 14: HandyPod for floating household adapted for dry and wet season

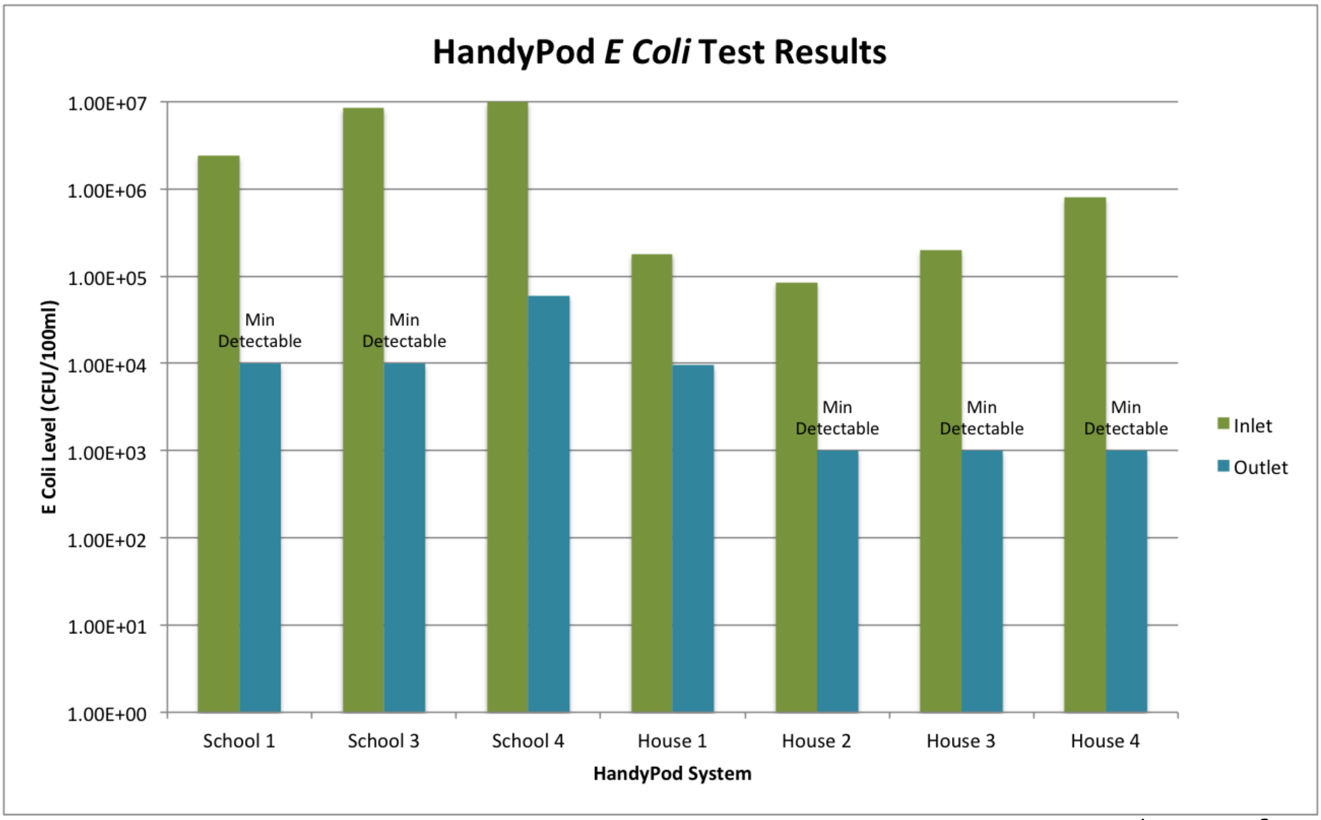
Figure 15: Larger HandyPod system, complete with final-stage hyacinth pond, at a floating school

3.3.2 TESTING

EWB recently supported Wetlands Work! to conduct a range of performance tests on the latest version of the HandyPod system, which has been in use for over 8 months. Samples were collected from both the smaller $0.5m^3$ household sized systems as well the larger $0.8m^3$ school systems. Samples measured the *E Coli* reduction across the system as well as the phosphorous, nitrogen and BOD levels in the effluent leaving the system.

The testing shows the HandyPod system produces a minimum *E coli* reduction of two-log order in all but one of the systems (House 1) (refer to Figure 16).

Figure 16: Results from HandyPod Testing showing E Coli reduction across the system.



Note for school and household systems minimum detectable level of 10^4 and 10^3 cfu/100ml respectively.

During the dry season the background E Coli levels in the lake water of the Tonle Sap, which is used by all households for their washing, cleaning, bathing and some cooking requirements, has been measured by Brown (2010) to be $1.0\text{-}1.5 \times 10^3$ cfu/100ml. This means the effluent leaving the systems in households 2, 3 and 4 is the same or better than the ambient surrounding water quality.

The testing showed the system outlet had an average BOD_5 of 136 mg/l, with a wide range of variability with the lowest BOD_5 recorded being 59 mg/l and the highest 246 mg/l. The Total Phosphorous and Nitrogen present at the outlet of the system was also elevated with an average of 239 mg/l of Nitrogen and 25 mg/l of Phosphorous, with a wide range of results between systems. The significant variability is thought to be caused, by usage rates and variable inflows as some household and school systems have many more users than others. Also, school systems often receive a lot more urine than faecal matter compared to the household systems.

While the testing and samples were being conducted a survey of user experience with the HandyPod system was conducted at the households and schools, and the systems received positive feedback. The household systems were all in regular use and were well maintained and clean, however some of the school systems were obviously only used intermittently and could be used more extensively. Where possible, further efforts will now be focused on determining if there are affordable and appropriate means of reducing the BOD_5, Nitrogen and Phosphorous levels in effluent before leaving the system.

The testing conducted has shown the HandyPod system is an effective sanitation technology for the floating communities in tropical conditions.

4 DISCUSSION

4.1 TECHNOLOGY COMPARISON

Each of the technologies discussed in this paper have been designed to suit a unique environment. Through the development of a range of options the EWB SCE project aims to ensure there is a sanitation option appropriate to the widest range of communities possible. Table 2, outlines technology cost, treatment efficiency and suitability.

Table 2: Comparison of sanitation technologies for challenging environments

Technology	**Description**	**Product Cost** (exclusive of super-structure)	**Challenging Environment**	**Treatment Efficiency (note 1)** (E Coli log-order reduction)	**Comments**
Pour-Flush Pit Latrine	Standard pour-flush concrete-ring pit latrine (e.g. Easy Latrine)	US$50	N/A - not appropriate for challenging environments	N/A - effluent can travel directly into soil or ground- or surface-waters	Low cost, well known, and easily accessible.
ATEC* Biodigester	ATEC* Bio-digester used as both sanitation & energy technology with direct connection of toilet to inlet of bio-digester.	US$680	• Flood-prone • High groundwater	2 log reduction	Significant capital cost is offset by reduction in household expenditure on fuel for cooking. Requires two cows (or four pigs).
3C Pit Latrine	Adaption to standard concrete pit latrine with septic-tank style functionality at reduced cost.	US$90	• High groundwater (primary) • Flood-prone (secondary)	2 log reduction	Custom concrete moulds for design cost ~$210 per set for mason's yard. Require additional care and attention in construction.
WW! HandyPod	Multi-stage treatment system for floating households using locally-available components.	US$150	• Floating • Flood-prone	2 log reduction	Product designed & developed by Wetlands Work! Adapted to amphibious conditions

Note 1: Treatment efficiency is based on preliminary results; further trials and testing are required in various circumstances to confirm specifications.

4.2 NEXT STEPS - ADOPTION AND COMMERCIALISATION

To achieve sanitation solutions that are appropriate and widely adopted by the community in Cambodia and other areas faced with challenging environments requires significant investment in developing supply chains, manufacturing processes and marketing strategies. The science and engineering components have been proven with adaptations continually incorporated in the face of setbacks or changing condition and user experiences.

Continued testing, trials and design refinement will be required for each technology described (and others) to confirm specifications, user responses and water quality outcomes. Ultimately to be able to reach all communities affected by challenging environments requires scalability in the manufacturing and sales process. Scalability of any new sanitation technology is a significant challenge in Cambodia, as importing products is both expensive and complicated, and there is limited manufacturing capacity for new products. Accessing financing to continue product development, market testing and to establish manufacturing lines is also a major obstacle.

The next steps for the technologies discussed in this paper, include:

ATEC* Biodigester (toilet attachment) - confirm results of household trial and incorporate learnings to enable a new product line for a 'standard toilet-connection' to the ATEC* Biodigester. A market-based approach to expand the product range will be applied.

3C Pit Latrine - a household trial is required to confirm functionality and specifications. Once the design is finalised with a suitable manufacturing and marketing plan the 3C Pit Latrine will be included in the iDE product range for roll-out. iDE have well established Sanitation Marketing approaches, with trained salespeople in Cambodia and regionally.

HandyPod (WW!) - demand creation is vital to achieve adoption of the Handypod, coupled with establishment of a supply chain with centralised packaging, delivery to remote villages for installation, and access to after-sales services (WaterAid 2017). Village savings groups have been targeted to help provide credit for purchasing, and subsidies by major donors are being investigated.

One of the key factors in developing each of these technologies has been the strong emphasis on knowledge sharing and collaboration within the Cambodian water and sanitation sector. By promoting open knowledge sharing of designs and experiences has enabled new innovations, access to supply chains and increased donor interest. The learnings taken from Cambodia should be evaluated and where appropriate applied in other challenging environments around the world.

5 CONCLUSIONS

To achieve 100% sanitation coverage world-wide requires focused efforts towards reaching scalability of appropriate solutions for all communities, including those in challenging environments. This paper has highlighted three promising technologies for sanitation in communities faced with flood-affected, high groundwater and flooding conditions based on experiences and learnings from application in Cambodia. Although these technologies are still under development, results indicate a two to three log-order reduction in pathogen levels before effluent enters the surrounding environment. This is a significant improvement on existing latrine technologies for these environments. Each technology has been developed in the context of scalability, without losing sight of the importance of understanding and adapting solutions to be affordable and appropriate to the needs of communities.

As these technologies are adopted on scale, there will be health and environmental benefits for surrounding water bodies and soils. The health outcomes of improved sanitation are widely documented, to include improvements to physical and mental development, with affected communities having more time for productive activities and less expenditure on health care (Hutton, 2015).

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