SEQUANA
WATER ENVIRONMENT ENERGY

Winnovators
Developing skills, ideas, futures

WATERAID SOLVE CHALLENGE 2025

TEAM: THIRST RESPONDERS

Healthcare facilities in Kampong Tralach District face critical wastewater management issues, with failing septic systems leading to groundwater contamination, heightened disease risk, and unsafe conditions for staff and patients.

Our challenge: To develop a scalable and tailored, climate-resilient, affordable, low maintenance and sustainable wastewater management solution for healthcare facilities in Kampong Tralach District that protects public health, ensures environmental safety, and supports safe, hygienic healthcare delivery.

OUR SOLUTION

Our proposed solution is RiceCycle: a low-cost, passive wastewater treatment solution designed for decentralised healthcare settings. Using a subsurface flow constructed wetland built from local materials, including rice husk waste and biochar, RiceCycle operates with minimal reliance on utilities, sensors, skilled labour, or ongoing maintenance.

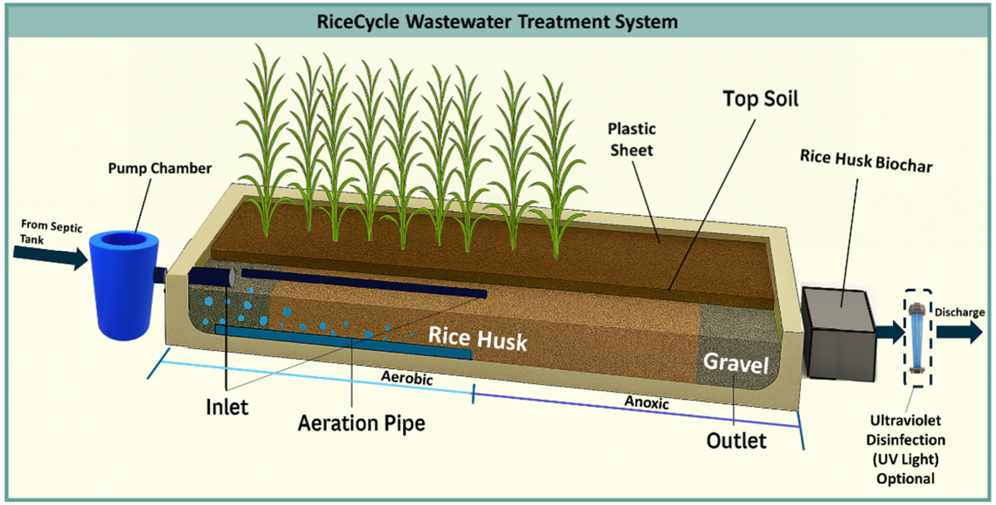


FIGURE 1: RICECYCLE PROCESS OVERVIEW

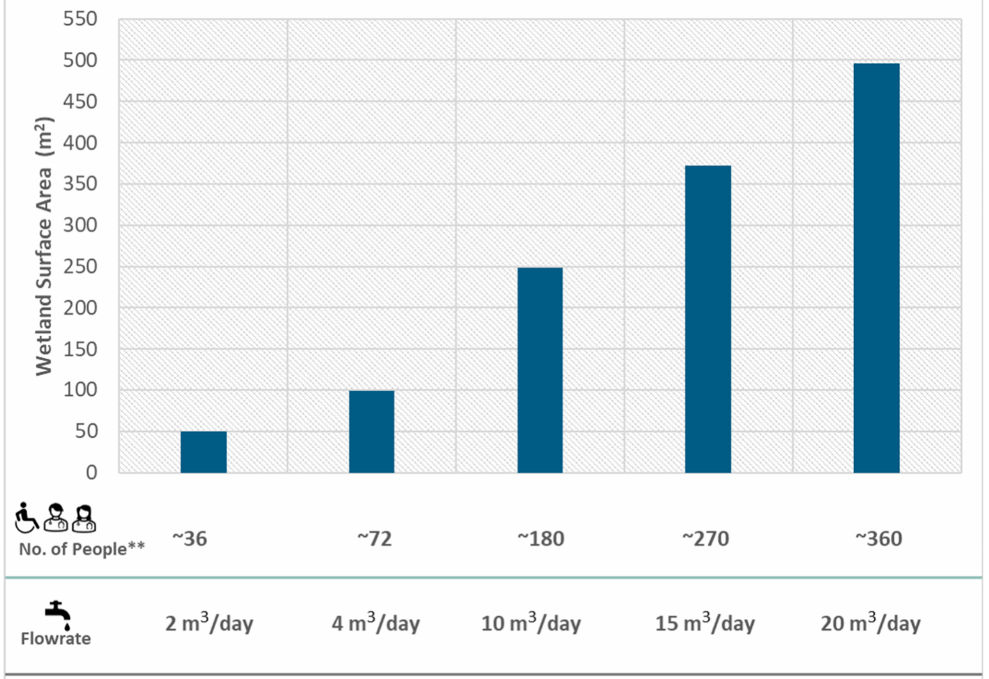
RiceCycle resolves a complex challenge while providing public health and environmental benefits. The solution draws on a robust biological treatment process that can be readily scaled and configured to suit site-specific requirements yet remains economical and easy to implement and maintain, maximising use of local resources. It is also climate resilient. It sets a solid foundation for a pilot model system that can be used to advocate for national standards.

The solution is modular and scalable, allowing it to be tailored to the available land area and the population it needs to serve. This flexible, “cookie-cutter” style approach enables consistent application across healthcare centres and districts with varying constraints and requirements.

BENEFITS

PUBLIC HEALTH	
Reduced Disease Transmission	If the UV treatment is added, the solution prevents the spread of communicable and waterborne diseases which are common in areas with poor sanitation.
Protects Vulnerable Groups	Pregnant women, children, the elderly, and people with weakened immune systems benefit most from reduced exposure to pathogens.
Education and Awareness	Offers educational value through visible and interactive infrastructure that engages communities in local language, in water treatment and environmental awareness. This is supported by in-country training sessions for key project representatives, who can then serve as civic champions to help spread knowledge across community groups.
ENVIRONMENT	
Safe Discharge Quality	Up to 80% removal of carbon and nitrogen pollution loads, allowing for compliant treated wastewater discharge (see calculator). Together with treatment of health facility specific contaminants, RiceCycle greatly reduces risks to human health and ecosystems.
Climate Resilience	Wetland to be constructed with a robust, reinforced outer edges (e.g. gabions, concrete or brickworks) and a structural top layer using soil and plastic sheeting. The subsurface design protects against runoff and flood-related disturbances even under full submersion, treatment can resume shortly after floods without significant works.
Contribution to Sustainable Development Goals (SDGs)	Directly supports SDG 3 (Good health and well-being), SDG 6 (Clean water and sanitation) and SDG 12 (Responsible waste management)

SCALABILITY	
Replicable Model	Modular, standardised design allows easy replication across healthcare centres – supporting a "cookie-cutter" approach. Refer to Figure 2 for a graphical representation of scalability.
Adaptable to Context	Scalable and flexible, adapting to varying inflow volumes and site constraints. Configuration can be amended if there are land constraints around available area (ie. excavations can be deeper, certain components can be substituted, etc.) Treatment steps can be added if required (e.g., UV).
IMPLEMENTATION	
Local Employment	Limited technical skills are required during the construction, operation and education phases of the project allowing both local men and women to have access to employment opportunities. Healthcare facility maintenance staff can likely perform many RiceCycle maintenance tasks.
Local Economic Stimulation	Using locally sourced materials and employing locals will help inject income into households and support local businesses.
Rapid Deployment	The system can be built within a single dry season, with an estimated construction timeframe of 2 months.
Cost Effective	<u>Total Approximate Costs – $15,891.00 USD (see Appendix)</u> Maintenance costs are expected to be under $600 USD/annum (excluding labour) due to the simple equipment design. Annual inspections of key components like the pump, blower, wetland and biochar media and UV system are recommended.
Easily Obtained Materials	Rice husks: Local rice mills (e.g., KTS Rice Mill, Te Mouy Rice Mill) Biochar: Husk Ventures SI Khan Mean Chey, Phnom Penh Building materials and components: Locally sourced Pumps: Donated by Xylem
Safety in Operation	The wetland area will be marked to prevent entry. Treated wastewater can disperse into the ground or a nearby creek. A low-maintenance UV unit can be added if frequent human contact is likely for effective disinfection.



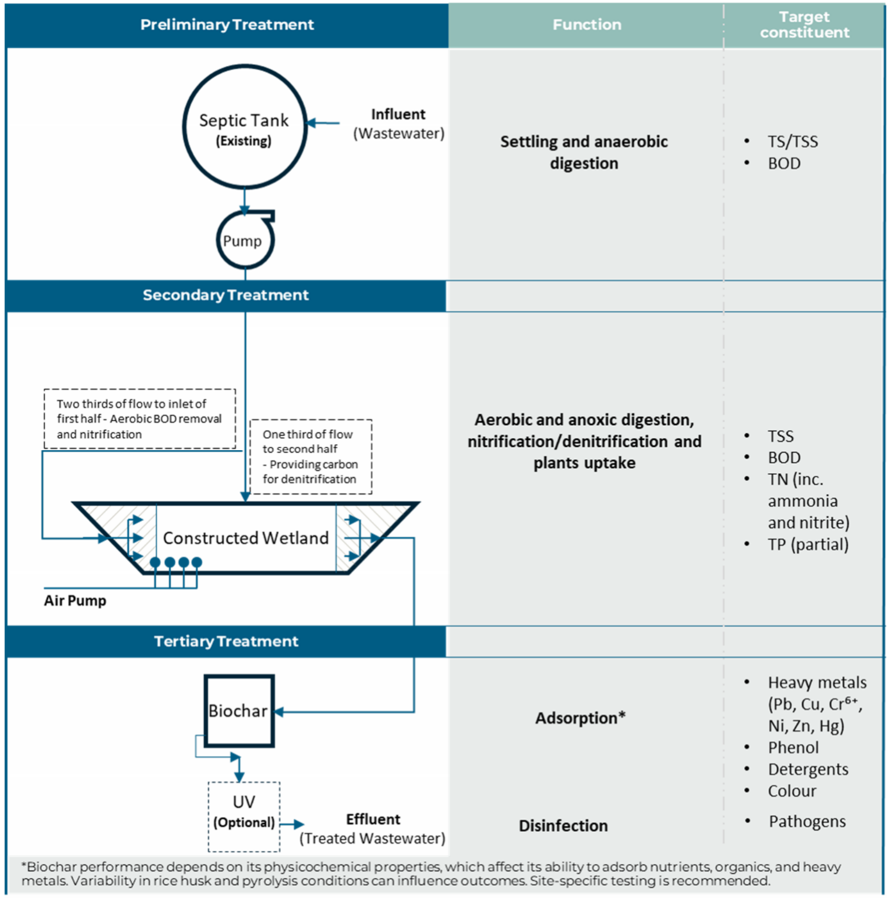
***"Number of people"* refers to all individuals contributing to facility wastewater, including inpatients, outpatients, staff, and visitors. Daily wastewater generation is assumed as: inpatients – 150 L/day, outpatients – 30 L/day, staff – 8 L/day, visitors – 20 L/day. For example, a 2,000 L/day system may serve ~5 inpatients (15%), 15 outpatients (40%), 8 staff (22.5%), and 8 visitors (22.5%).

FIGURE 2: GRAPHICAL DEMONSTRATION OF SCALABILITY OF THE SOLUTION DEPENDING ON CONSTRAINTS

METHODOLOGY

Component	Purpose and How It Fits into the Process
Septic Tank (Preliminary Treatment)	**First stage.** Wastewater enters the existing septic tank, where solids settle and some organic pollutants (BOD) are broken down anaerobically. This pre-treatment makes the water easier to treat in the next stage.
Pump Chamber	**Second stage.** The wastewater flows into a chamber where it's pumped according to the tank level intermittently into the wetland system.
Aerated Constructed Wetland (Vegetated Submerged Bed) (Secondary Treatment)	**Third stage.** Water enters a vegetated, soil-covered wetland filled with porous media such as rice husk and gravel. First half: Air is introduced via a simple blower system, creating aerobic conditions that break down organic matter and ammonia-nitrogen (nitrification). Second half: Water moves into an anoxic zone to support denitrification, further removing ammonia-nitrogen. Plants like *Typha latifolia* (broadleaf cattail) and *Scirpus tabernaemontani* (soft-stem bulrush) can be placed, ideal for flood mitigation and tolerant to ammonia, absorbing nutrients, improving water quality, and also enhancing aesthetics.
Biochar – Tertiary Treatment	**Fourth stage.** The treated wastewater flows through a biochar-packed filter (e.g., IBC tank) made from local rice husk biochar. This final step removes residual pollutants like pharmaceuticals, heavy metals, and trace contaminants, resulting in clear, low-pollution treated-wastewater.

FIGURE 3: LOCAL RICE HUSK (LEFT) USED IN THIRD STAGE AND RICE HUSK BIOCHAR (RIGHT) USED IN FOURTH STAGE OF THE RICECYCLE WASTEWATER TREATMENT SYSTEM



DELIVERY CONSIDERATIONS

1. Confirm system performance through baseline sampling
2. Monitor contaminant removal at each treatment stage and adjust (e.g., aeration rate, media depth)
3. Sample if feasible post-biochar treated wastewater to assess effectiveness, including heavy metals.
4. Replace biochar every 6 to 12 months. Maintain plants, plastic covers, and top-up rice husk media as needed
5. Conduct community training and outreach

APPENDICES

ADOPTED PARAMETERS FOR DESIGN

For the standardised approach adopted in our design, we used Thlok Vien Health Centre in Kampong Chhnang Province, Cambodia, as a representative case study. The centre is located in Thlok Vien Commune and serves a rural population that increased from approximately 5,011 in 2004 to 6,677 by 2019. The facility is assumed to employ between 8 and 10 staff members. For a facility of this scale, the overall flow rate was estimated at 2,000 L/day. An available land area of 60 m² was assumed for the wetland system, consistent with the dimensions discussed during the Winnovators workshop sessions. Clay soil was assumed to be the dominant local soil type, and it was also assumed that the existing on-site earthen septic tank would remain in use, providing preliminary treatment prior to the wetland.

In terms of wastewater quality, although below 20m3/h and not subject to national regulation, our solution complies with Sub-Decree No.103 ANKr/BK (2021), targeting the key parameters listed in Table 1 as the basis for our design calculations and performance assessments.

TABLE 1: COMPARISON OF INFLUENT CHARACTERISTICS, NATIONAL DISCHARGE STANDARDS, AND EXPECTED TREATER WASTEWATER QUALITY FROM PROPOSED SOLUTION (2000L/DAY).

Parameter	Influent	Effluent	
	Typical HWW Range (Developing Countries)	Open Water discharge standard[1]	Expected treated wastewater quality of solution
pH	6.0 – 9.0	6.0 – 9.0	6.0 – 9.0
BOD$_5$	120 - 300 mg/L	<60mg/L	~3 mg/L
TSS	150 - 250 mg/L	<100 mg/L	<<80 mg/L
Total N	5 - 80 mg/L	<40 mg/L	~30 mg/L
	60 mg/L Adopted		
Total P	0.2 - 13 mg/L	<6.0 mg/L	Dependent on plants uptake
Biochar adsorption	Advanced contaminants testing prior and post treatment is required to evaluate the performance of sorption capacity of biochar. Tests recommended ICP-OES for heavy metals and other cations, gallery thermos-scientific for nitrite reduction.		
Faecal Coliforms	103 −107 MPN/100 mL	(Standard typically very low or absent for discharge)	Dependent on the use of UV

[1] Please note that for our sizing calculations, the calculator can be adjusted for both open water and closed water conditions. It is currently set to open water discharge.

DESIGN APPROACH

Our team combined wastewater treatment knowhow and a number of wetland-based treatment case studies to design a specific innovative solution meeting the requirements of the challenge while leveraging the local context and available resources. Treatment performance was verified against applicable literature for each process steps.

A horizontal subsurface flow constructed wetland was designed using a staged approach incorporating a pre-existing septic tank, wetland with an aerated zone, and anoxic zone, and post treatment biochar filter. Septic tank performance was assumed to follow standard international guidance, with typical removal of 20–50% of BOD and TSS (Tilley et al., 2008; US EPA, 2000).

The design followed an iterative two-stage process, beginning with a conservative initial sizing and followed by a more refined configuration that accounted for aeration. The first iteration adopted a generic approach derived from the US EPA's Constructed Wetlands Manual for Municipal Wastewater (US EPA, 2000), assuming no active aeration. This approach was used to size a conventional, non-aerated constructed wetland system, primarily targeting BOD (organic carbon) removal. It served as a baseline for estimating the required footprint and allocating flow between treatment zones.

The second iteration built upon the initial layout by integrating an aerated section at the front of the system. The purpose of this addition was to optimise ammonia removal, reduce organic loading upstream, and allow a more granular understanding of nitrogen transformation processes, particularly nitrification and denitrification, rather than assessing total nitrogen as a single bulk parameter (Metcalf & Eddy, 2014). The first segment was modelled as an aerated, attached-growth biofilm reactor, with media selected for its high surface area to support microbial activity (Kadlec & Wallace, 2008; Metcalf & Eddy, 2014).

This was followed by an unaerated, anoxic segment designed to facilitate denitrification (Kadlec & Wallace, 2008). Flow was split accordingly, with approximately two-thirds of the influent entering the system at the head of the aerobic zone, and the remaining one-third introduced at the start of the anoxic section to provide an external carbon source, enhancing nitrate reduction through denitrification. .The design adopted kinetic expressions aligned with the first-order decay principles described in (Metcalf & Eddy, 2014) and explicitly supported by (Kadlec & Wallace, 2008), who recommend first-order modelling for a wide range of wetland processes, including biological degradation, mass transfer, sedimentation, and sorption. Each zone was therefore modelled using first-order kinetics under steady-state, plug-flow assumptions, with the aerobic segment additionally considered to behave as an attached-growth system. This reflects the configuration of the reactor media, which provides a high surface area conducive to biofilm formation and stable nitrification performance. Depending on internal hydraulics, the aerobic section may also exhibit characteristics closer to a completely mixed reactor.

Wastewater BOD, concentrations in the aerobic (attached-growth) segment were estimated using the standard first-order decay model for completely mixed systems:

$$S = S_0 . e^{-K\theta} \qquad \textbf{Eq 1}$$

Where, S is the constituent concentration in the wastewater (mg/L), S_0 is the influent concentration (mg/L), k is the first-order rate constant (/day), and θ is the hydraulic retention time (days). Eq. 1 was applied throughout (aerobic and anoxic zones), with adjustments to rate constants depending on whether the zone was aerobic (for BOD and ammonia oxidation) or anoxic (for nitrate reduction).

For denitrification in the downstream wetland zone, the same first-order equation was applied, adopting an oxidised nitrogen removal rate constant derived from (Kadlec & Wallace, 2008). The selected value represents the 95th percentile for vertical subsurface flow wetlands and was converted to a daily areal rate by accounting for wetland depth and operational time. This calibrated rate constant was then applied to model nitrate removal via denitrification, supporting the assumption that full conversion of NO_3–N to N_2 gas could be achieved in the anoxic segment.

Aeration requirements were estimated based on the combined oxygen demand for BOD oxidation and ammonia nitrification, using stoichiometric factors from Metcalf & Eddy (2014)'s Chapters 7 and 8. The actual oxygen transfer efficiency (AOTE) was adjusted for site-specific conditions using the equation:

$$AOTE = SOTE.\alpha.\beta.\left(\frac{C_S - C_L}{C_S}\right).(1.024)^{(T-20)}.F \qquad \textbf{Eq2}$$

where SOTE is the standard oxygen transfer efficiency in clean water, α is the wastewater correction factor, β accounts for salinity/surface tension, C_s is the DO saturation concentration (mg/L), C_L is the operating DO level (mg/L), T is temperature (°C), and F is the fouling factor. Further operational testing will be required to confirm how the system behaves dynamically. Sizing of a wetland suitable for a 2,000 L/day flowrate is summarised in Table 2.

TABLE 2: WETLAND DESIGN PARAMETERS BASED ON FIRST-ORDER KINETICS FOR A 2,000 L/DAY CONSTRUCTED WETLAND SYSTEM WITH AEROBIC AND ANOXIC ZONES (NO EXTERNAL CARBON SOURCE ASSUMED)

Parameter	Value (approx.)	Unit
Wetland Hydraulic Retention Time	5	Days
Wetland Area	50	m^2
Length: Width Ratio	3	–
Wetland Width	4	m
Wetland Length	12	m
Wetland Depth	0.5	m
Wetland Volume (Gross)	25	m^3
Length of Aerobic Zone	4.5	m
Length of Anoxic Zone	7	m

It is important to note that the current wetland sizing is based mainly on biological treatment processes, with minimal consideration to nutrient uptake by vegetation. In reality, plant uptake of nitrogen and phosphorus is expected to further enhance treated wastewater quality. This contribution, though more seasonal and variable, may lead to additional reductions in nutrient concentrations and could potentially allow for a smaller wetland footprint and retention time than originally calculated.

Such a hybrid design aligns with global practice. Aerated constructed wetlands have been shown to reduce land area requirements by a factor of 4–5 compared to conventional passive systems (IRIDRA Srl, 2025). Organisations like IRIDRA Srl, a European leader in nature-based sanitation solutions, have successfully implemented similar integrated designs in WASH programs across India, Vietnam, and Tanzania. Their systems combine targeted aeration with natural treatment mechanisms to deliver reliable, decentralised sanitation outcomes with minimal land use (WASH - IRIDRA Nature Based Solutions - NBS).

FIGURE 4 AERATED CONSTRUCTED WETLAND IN DEVELOPING AREA BY IRIDRA SRL

The wastewater from a healthcare facility is expected to contain high concentration of specific contaminants than typical domestic wastewater, including disinfectants, pharmaceuticals and reagents for the laboratory. While the disinfectant will be consumed and degraded in the biological process, the pharmaceutical and reagent molecules will largely remain present. Therefore a final polishing step has been added in the form of a 1 m³ rice husk biochar tank (i.e., IBC tank) to adsorb residual contaminants in the treated wastewater. The original concept was to use locally available biochar derived from rice husk gasification, a common by-product of rural biomass energy systems found in Cambodia and used for electricity generation. However, for practicality, and to avoid biochar processing (e.g., granularisation and palletisation) we explored the potential use of biochar produced by Home - Husk | Fertilizers used to regenerate soils, a company known for converting rice husk waste into biochar at scale. However, the quality and characteristics of available biochar products remain largely unknown and can vary significantly depending on feedstock, pyrolysis conditions, and handling processes.

For design purposes, we adopted a conservative adsorption capacity of approximately 40 mg/g, based on literature values for rice husk biochar across a range of contaminants (Kizito et al., 2015; Leng et al., 2015). This was used to estimate the treatment capacity / rinsing requirement / expected lifespan of the unit:

$$Sorption\ Capacity\ (Days) = \frac{(q.\rho.V)}{C.Q} \qquad \textbf{Eq3}$$

where q is the adsorption capacity of biochar (mg/g), ρ is bulk density of biochar (kg/m³), V is the volume of biochar used (m³), C is concentration of contaminant in influent (mg/L) and Q is the flow rate (m³/day)[2]. As such. regular maintenance is recommended, including bimonthly mild acid rinsing (e.g., vinegar or HCl diluted to pH ~4) to partially regenerate adsorption sites. Full media replacement is expected to be required approximately every year. Actual performance and replacement timing, however, will depend heavily on the specific biochar use, particularly its porosity, ash content, surface are and chemistry, and the degree of biological activity within the system.

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[2] Assuming q = 40 mg/g, ρ = 300 kg/m³, V = 1 m³, C = 10 mg/L, and Q = 2 m³/day, biochar lifespan ≈ 60 days. Rinse with acid, replace after 12 months (6 cycles).

TABLE 3: DETAILED COST BREAKDOWN

Description	Rate (USD)	Rate	Qty	Ext. Qty	Total	Comments
Materials Subtotal					$ 7,301.00	
Septic Tank	$ 1,000.00	$/ea	1	1	$ 1,000.00	
Pump Chamber	$ 600.00	$/ea	1	1	$ 600.00	
Submersible Pump	$ -	$/ea	1	1	$ -	Donated by Xylem - equivalent cost $350 USD
Level Switches	$ 130.00	$/pair	1	1	$ 130.00	
Blower Plinth	$ 400.00	$/ea	1	1	$ 400.00	
Blower	$ 130.00	$/ea	1	1	$ 130.00	
Electrical	$ 325.00	$/ea	1	1	$ 325.00	
25mm DWV	$ 15.00	$/length	4	1	$ 60.00	6m lengths
80mm DWV	$ 60.00	$/length	2	1	$ 120.00	6m lengths
100mm DWV	$ 65.00	$/length	2	1	$ 130.00	6m lengths
Misc. fittings (couplings/glue/bends etc)	$ 130.00	$/ea	1	1	$ 130.00	
Garden hose coil (12mm x 30m)	$ 20.00	$/ea	1	1	$ 20.00	
Liner supply	$ 3.00	$/m2	42	1	$ 126.00	
Gravel	$ 7.50	$/m3	10	1	$ 75.00	
Media (rice husk)	$ 80.00	$/tonne	5	1	$ 400.00	2.6 tonne are needed - $80/tonne is inclusive of transport
Topsoil	$ 35.00	$/m3	6	1	$ 210.00	
Plants	$ 10.00	$/ea	50	1	$ 500.00	
IBC (second hand)	$ 35.00	$/ea	1	1	$ 35.00	
Rice Husk Biochar	$ 120.00	$/m3	2	1	$ 240.00	1 m3 is required per filter - Allowed for one replacement of media
UV Light	$ 320.00	$/ea	1	1	$ 320.00	
Misc. tools for construction	$ 2,000.00	$/total	1	1	$ 2,000.00	Allowance for establishment, assume tools can be obtained locally
Delivery	$ 70.00	$/load	5	1	$ 350.00	
Personnel Subtotal					$ 8,030.00	
Engineer	$ 50.00	$/day	42	1	$ 2,100.00	
Supervisor	$ 50.00	$/day	42	1	$ 2,100.00	
Unskilled labour	$ 6.00	$/day	42	15	$ 3,780.00	
Electrician	$ 10.00	$/day	5	1	$ 50.00	
Education - Community Awareness Sessions					$ 560.00	
Engineer	$ 50.00	$/day	5	2	$ 500.00	
Local representative (unskilled labour)	$ 6.00	$/day	5	2	$ 60.00	
TOTAL					**$ 15,891.00**	