Technical guidelines for designing a decentralised waste water treatment system

Programme Support Unit
WaterAid

Macrophytes on wetlands, Bangladesh.

Prepared by: Abdullah Al-Muyeed. Unless indicated all diagrams by Abdullah Al-Muyeed.

Reviewed by: Erik Harvey, Ada Oko-Williams, Rémi Kaupp, Arjen Naafs, Mark Fabian

April 2017

Summary

This guidance document is intended for WaterAid programme staff and our partners. It helps with the implementation of a decentralised waste water treatment system or DWTS, based on the experience of several WaterAid country programmes and especially WaterAid Bangladesh.

A DWTS can be used to treat the waste water coming from houses and institutional settings, and represents an alternative to centralised treatment involving sewers and large treatment plants, and therefore large capital costs and running costs. A DWTS can be relatively compact, cheaper to install, and requires little maintenance and no energy input.

A DWTS typically consists of several elements: a septic tank, an anaerobic baffled reactor, an anaerobic filter, and a series of constructed wetlands. The exact dimensions and types of installations depend on many parameters, which are covered in this guideline.

Contents

Acronyms

ABR	anaerobic baffle reactor
BOD	biological oxygen demand
BORDA	Bremen Overseas Research and Development Association
COD	chemical oxygen demand
CP	country programme
CSE	centre for science and environment
CSTR	combined with continuous stirred tank
DWTS	decentralised waste water treatment system
HF	horizontal flow
HRT	hydraulic retention time
HSSF	horizontal subsurface flow
LDPE	low density poly ethylene sheet
O&M	operation and maintenance
UV	ultraviolet ray
VF	vertical flow
VSSF	vertical subsurface flow
WASH	water, sanitation and hygiene
WHO	World Health Organization

Outlet on a polishing pond, Bangladesh.

Introduction

As urbanisation rapidly progresses across the world, the demand for on-site sanitation is also increasing. In order to achieve sustainable sanitation services, we need to overcome the limitations of conventional centralised waste water treatment (sewerage) systems. 'Decentralised Waste water Treatment System' (DWTS) refers to an integrated systems approach to treating domestic waste water.

DWTS may be defined as 'the collection, treatment, and disposal/reuse of waste water from individual homes, clusters of homes, isolated communities, industries, or institutional facilities, as well as from portions of existing communities at or near the point of waste generation'[1]. In the case of DWTS, both solid and liquid fractions of the waste water are used near their point of origin, except in some cases when a portion of liquid and residual solids may be transported to a centralised point for further treatment and reuse. This guideline incorporates lessons learnt from experiences of different WaterAid country programmes (CPs), and considers WASH services that are accessible to poor people.

DWTS is characterised by the following features:

- DWTS is an approach rather than a construction. The operation and maintenance of such a system need to be considered during the planning phase of the project.
- DWTS can be implemented using local skills and technologies to provide context-specific sanitation services. The system has the ability to treat domestic waste water from primary to tertiary level, and it is generally a community/committee-managed system.
- A city sanitation plan can incorporate such a system where on-site sanitation service is required.
- The system can treat waste water and treat entailing effluent for standard discharge. Since WaterAid works in many parts of the world and many countries have different effluent discharge standard, this guideline has been prepared under the notion of providing technical know-how to meet the standard. However, each WaterAid CP is advised to check their own country standards of effluent discharge while designing a DWTS.
- DWTS can provide a renewable energy source. Depending on the demand, technical modifications can be made and biogas can be generated to supply energy. Moreover, the effluent can also be used for aquaculture and irrigation. However, this guideline has been prepared focusing primarily on safe environmental discharge. The reuse of treated waste water needs particular attention on health and safety aspects and each CP needs to pay special attention to reuse, which is described later in this guideline.
- The system has the capacity to run without any further external energy source. It is not recommended to use a pump in the system. However, considering the limited available land, a pump may be added, but it is recommended to use a renewable energy source for such a pump system.

This guideline does not focus on pumping system for lifting and conveyance of waste water.

- The basic system components can be configured as per the context of the project. However, proper technical know-how is required to get optimum efficiency of the system. It is not recommended to alter the basic system components where DWTS will be implemented in WaterAid CPs.
- The system can elongate the desludging period by treating the waste water part. However, desludging will still be required when the septic tank becomes full.

Suitability

On-site treatment system and DWTS

On-site treatment systems can be adopted when the individual houses are scattered over a large area, and where centralised systems do not exist. This can also be a preliminary option in newly developing localities. However, it is emphasised here that the option of on-site treatment system should be considered mostly as an interim solution, and not a permanent waste water treatment/management option. If improperly designed or maintained, or left unattended, on-site treatment systems can result in severe environmental hazard.

Various on-site waste water treatment systems are available. Selecting the most appropriate option requires a thorough analysis of all factors including cost, cultural acceptability, simplicity of design and construction, operation and maintenance, hydrogeological conditions and local availability of materials and skills. DWTS is an on-site sanitation system that treats waste water (both black and grey water) mostly at community scale, or even larger scale.

Waste water management systems can be either conventional centralised systems or decentralised systems. Centralised systems are usually planned, designed and operated by government agencies, which collect and treat large volumes of waste water for entire communities. On the other hand, DWTS systems treat waste water of individual houses, apartment blocks or small communities close to their origin. Typically, the DWTS is a combination of many technologies within a given geographical boundary, namely one of multiple onsite sanitation systems comprising of low-cost collection systems and dispersed siting of treatment.

It may also be noted that any city or town can have a combination of centralised, decentralised and on-site waste water treatment systems, to meet the overall city sanitation.

Decentralised vs centralised treatment system

Design and management of DWTS can be achieved at a fraction of the cost required for typical centralised treatment plants. Table 1 summarises some salient features of DWTS compared with conventional centralised treatment technologies.

Table 1: Comparison between centralised and DWTS[2]

	Centralised systems	DWTS
Reliability	Require complex operation and maintenance schedules to ensure optimal performance.	Do not require intensive maintenance for better performance.
Environmental sustainability	May generate partially treated or untreated waste water that may not meet discharge standards. Also require higher energy supply.	Treated waste water can be used locally, or can be safely disposed into local water channels. Energy requirement is low.
Financial sustainability	Substantial grants, government funding and subsidies are required for construction, operation and maintenance.	Require less capital cost when compared with centralised sewerage systems.
Affordability	Scores low on affordability due to substantial cost of installation, sewerage network, operational and maintenance costs.	Affordable due to lower costs when compared with centralised systems. Requires locally available materials, as a major portion of such systems is based on natural technologies.

A decision tree to select waste water treatment system (decentralised or centralised) at a community scale is given in Figure 1.

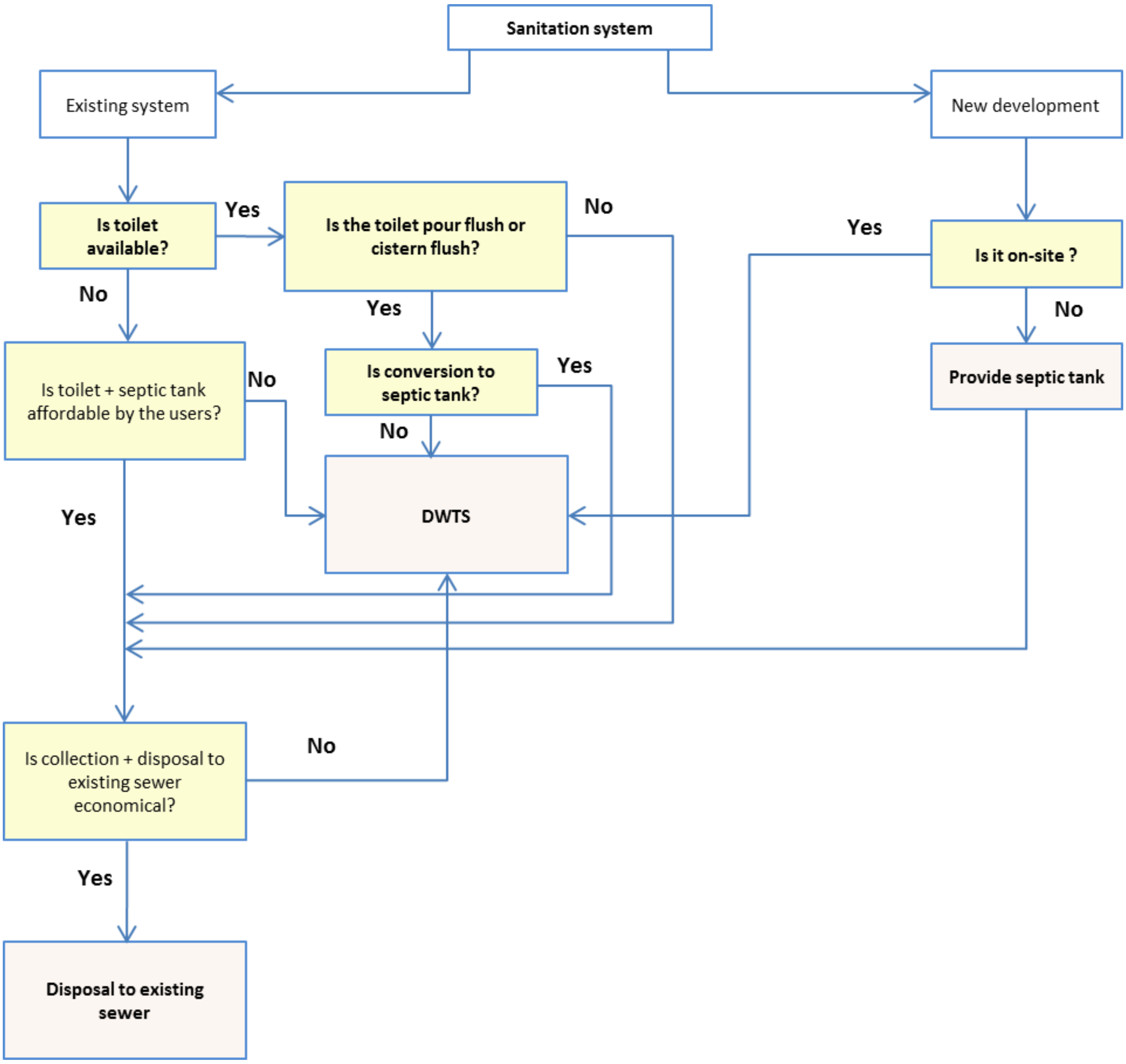


Figure 1: Decision tree for waste water treatment system.

Advantages

The main advantages of DWTS are:

- DWTS can be constructed according to influent waste water characteristics.
- It can treat waste waters from different sources such as residential structures, hospitals, schools, markets, hotels.
- Demands lower primary investment costs as no imports are needed.
- Requires lower maintenance costs.
- Can provide efficient treatment of waste water flow up to 1000 m^3/day.
- Tolerant towards inflow fluctuations.
- Reliable and long-lasting construction design.
- If properly managed, these systems can meet discharge criteria.
- Provides effective solution for ecologically sensitive areas.

Disadvantages

- Policies regarding installation, operation and maintenance are not well established in many developing countries.
- Standardisation of the systems is difficult as significant variations exist with regard to technical design to suit the local geography and climatic conditions.
- Individual households/establishments/communities will have to bear the operation and maintenance cost of the treatment systems.
- Improper maintenance of the treatment plant will have significant environmental consequences.

Suitable situations

The following situations are suitable for implementation of DWTS:

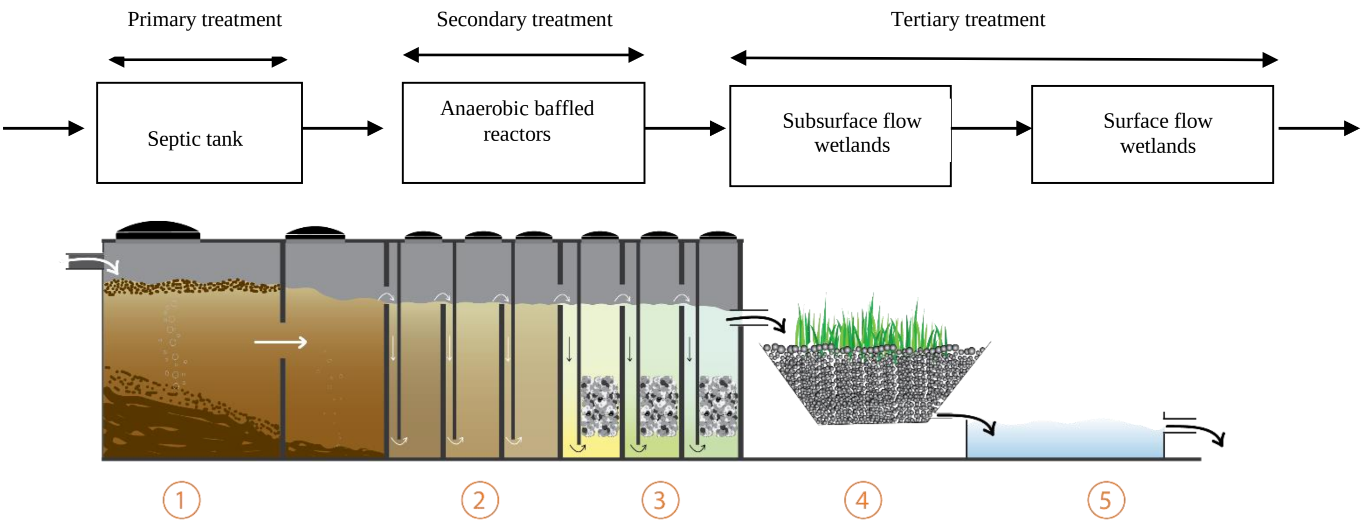
- Where clusters of on-site systems exist, and there is no control of the fate of the pollutants.
- Improper maintenance of on-site treatment systems and exorbitant cost of conventional remediation by implementation of centralised systems.
- Community/institutional facility is far away from the existing centralised system.
- Localities where there is scarcity of freshwater.
- Localities where there is a possibility for localised reuse of treated waste water.
- Localities where discharge of partially treated waste water is prohibited due to various environmental reasons.
- Localities where extension of existing centralised system is impossible.
- Newly developed or existing clusters of residences, industrial parks, public facilities, commercial establishments and institutional facilities.

System components

Waste water treatment in a DWTS is achieved via:

a) Primary treatment (settlers or septic tanks).
b) Secondary treatment (anaerobic baffled reactors).
c) Tertiary treatment (subsurface vertical flow and/or horizontal flow wetland systems).
d) Post-treatment (polishing ponds or surface flow wetlands).

Figure 2 illustrates an operational diagram of a typical DWTS train.



Section 1	Section 2	Section 3	Section 4	Section 5
Primary treatment	**Secondary treatment**		**Tertiary treatment**	**Post-treatment**
Septic tank	Baffled reactor	Anaerobic filter	Constructed wetland	Polishing pond/ Surface flow wetland
Sedimentation tank stabilising settled sludge by anaerobic digestion Dissolved and suspended matter leave tank untreated Removal of COD 20-25%, BOD 15-20%, TSS 50-55%	Anaerobic degradation of suspended and dissolved solids 2–5 chambers depending of treatment required Removal of COD 25-30%, BOD 30-35%, TSS 10-15%	Water passes through filter media Enhance digestion of organic matter Removal of COD 20-25%, BOD 15-20%, TSS 15-20%	Open shallow basin filled with gravel/pebbles to support growth of plant/reeds with shallow roots Reduces organic contents and acts as filter mechanism Removal of COD 15-20%, BOD 20-25%, TSS 5-10%	Open shallow basin for removal of stabilised or inactive suspended substances Exposure to UV rays Removes odour and pathogens

Figure 2: System components of DWTS[3].

Planning and designing

Appropriate planning and designing are critical prior to the construction of a DWTS.

The planning for employing a DWTS should include[4]:

- Identification of a site.
- Land availability of the proposed site.
- Topography of the land - detailed examination of soil, slopes, and hydrological parameters are critical.
- Location of groundwater.
- Source and volume of generated waste water.
- Local climate conditions.
- Socioeconomic environment of the local area and target population.
- Identification of reuse options (if required).
- Rigorous analyses of construction, operational and maintenance costs.

The main objective of a DWTS is to remove pollutants from waste water, so that it can either be disposed into the environment safely, or be reused. To meet such objectives, an engineer must consider the following factors, prior to the design procedures[4]:

- The volume of incoming waste water – daily and peak hourly incoming flow should be identified.
- Parameters of incoming waste water – for example BOD, COD, suspended solids, pH and temperature – should be measured.
- Local discharge standards should be examined carefully.

Community-based sanitation programmes with DWTS

The goal of any sanitation programme with the intervention of DWTS in WaterAid CPs should be long-term sustainability with maximum positive impact. From the preliminary needs assessment in the very early stages of a programme, up to the disposal and treatment of sludge, a multitude of tasks have to be completed. The efficient setting-up and implementation of such a programme require early identification of the necessary tasks and the people responsible for carrying them out.

Community involvement is appropriate in areas where financial resources are very limited and most residents live in rented rooms or huts, leaving no space for in-house sanitation, as in the case of clusters or slums in WaterAid CPs. The DWTS is established at a strategic location within the cluster settlement, and offers different services as requested by the community. Services can include water points, toilets, bathrooms and laundry areas. A smaller cluster of about ten to 50 households is connected to a community septic tank. Each cluster can be connected to a DWTS, usually located underground, and guarded and operated by the community.

Constructed wetlands

Classification

Constructed wetlands are engineered wetlands that have saturated or unsaturated substrates, emergent/floating/submerged vegetation, and a large variety of microbial communities. The wetlands are built for water pollution control. Constructed wetlands can be classified into two groups: (a) surface flow; and (b) subsurface flow wetlands.

Surface flow wetlands are similar to natural wetlands, with shallow flow of waste water (usually less than 60cm deep) over saturated soil substrate. Such wetlands look similar to natural wetlands. The pollutant mechanisms in surface flow systems include: sedimentation, filtration, oxidation, reduction, precipitation and adsorption. Figure 3 illustrates a diagram of surface flow wetland systems, employed for waste water treatment.

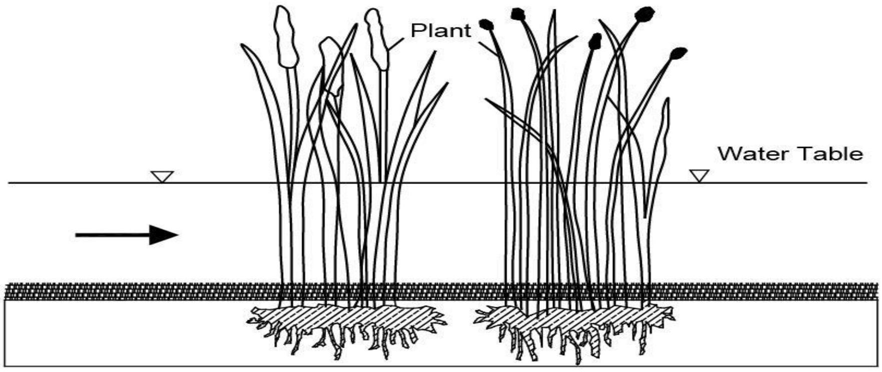


Figure 3: Surface flow wetland systems for the treatment of waste water.

In subsurface flow wetland systems, waste water flows beneath the media surface, where it comes into contact with an interconnected mesh of plants, media and attached biofilms. Depending on the flow pattern, subsurface flow wetlands can further be classified into: (a) vertical subsurface flow (VSSF); and (b) horizontal subsurface flow (HSSF) wetlands.

VSSF wetlands employ packed media with plants, and waste water flows vertically downwards through the media (under the force of gravity) towards the outlet. The main media is overlaid on large stones, to facilitate effluent drainage. The macrophytes (i.e. plants) are usually planted in coarse gravel, which provides the top surface.

Waste water is dosed intermittently into the bed surface of VSSF wetlands, allowing alternative wet and dry periods. During the interval between the successive doses, the bed remains unsaturated, which allows diffusion of oxygen inside the media. When the waste water is being dosed, it traps this pore air ensuring better oxygen transfer throughout the bed. As such, these systems promote higher oxygen distribution, effective for NH_4-N and BOD_5 removal from waste water.

Figure 4 provides a graphical and pictorial view of VSSF systems for waste water treatment.

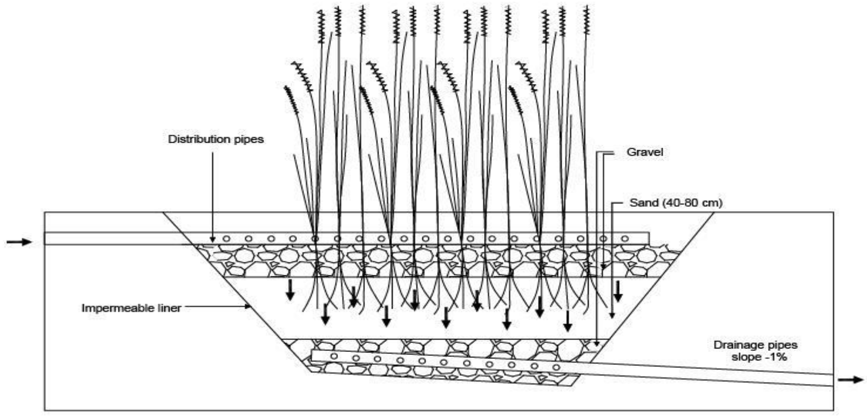


Figure 4: Schematic diagram of VSSF systems.

In HSSF systems, the media is kept saturated; the outlet is generally located at a height of 60cm from the bottom of the tank. Waste water flows horizontally from the inlet towards the outlet, beneath the media surface. During this passage of water, it comes into contact with a network of media, attached microorganisms and root zones. Since these wetlands are operated under saturated conditions, anoxic-anaerobic environments are predominant throughout the media, fostering denitrification. Figure 5 provides the components and flow path of HSSF systems.

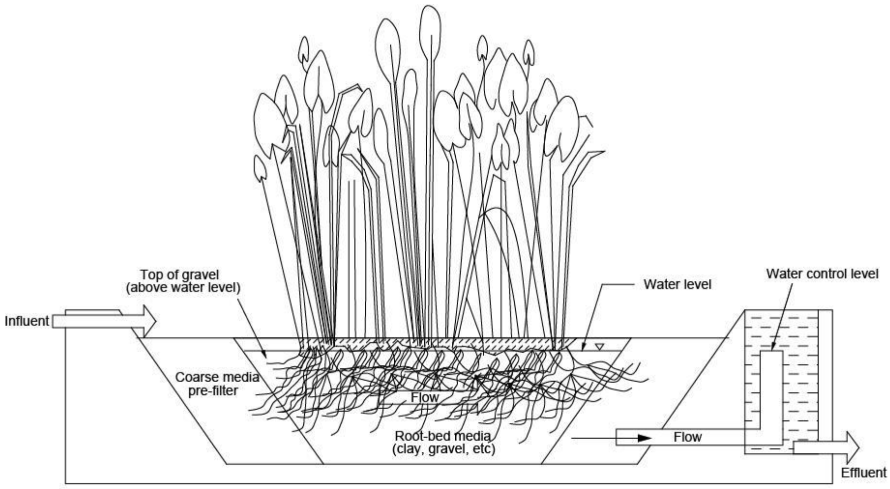


Figure 5: Schematic diagram of HSSF systems.

A combination of VSSF-HSSF or HSSF-VSSF systems, known as hybrid wetland systems, can also be employed for waste water treatment. These systems are effective in terms of utilising aerobic and anaerobic phases of VSSF and HSSF systems respectively, thereby achieving higher pollutant removal rates from waste water[5].

Figure 6 shows three parallel hybrid wetland systems. Each system consists of a VSSF system, followed by a HSSF system, to provide treatment of waste water. In most of the VSSF systems, pumping might be required, though it can be designed with gravitational force only where land is available. However, considering constriction of land availability, pump use may be incorporated in DWTS to achieve optimum efficiency.

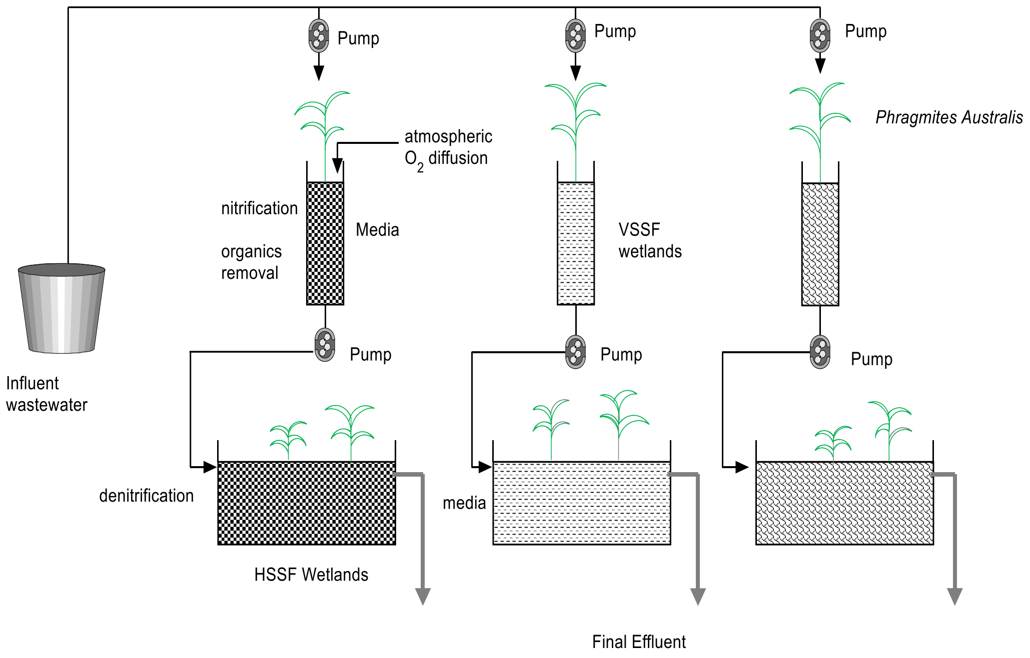


Figure 6: Hybrid wetland systems.

Table 2 indicates the advantages and disadvantages of VSSF and HSSF wetland systems when employed for waste water treatment.

Table 2: Advantages and disadvantages of VSSF and HSSF wetlands.

Type	Advantages	Disadvantages
Vertical flow wetlands (VSSF)	Smaller area demand.	Short flow distances.
	Good oxygen supply, good nitrification, better organics and solids removal, simple hydraulics.	Poor denitrification, higher technical demand, low nitrate removal.
	Higher purification from the beginning, better than HF beds as water flows from surface to bottom, which enhances oxygen mixing.	Loss of performance in phosphorous removal.
Horizontal flow wetlands	Long flowing distance, nutrients gradients can be established, efficient in the removal of solids, organics.	High area demand, clogging problem is observed, sulphur transformation can affect nitrification sensitivity.

(HSSF)	Denitrification possible.	Careful calculation of hydraulics necessary for optimal oxygen supply, low ammonium oxidation.
	Formation of humic acids for N, P removal.	Equal waste water supply is complicated.

Components

Plants, microorganisms, and wetland media are the main components of constructed wetlands. These elements form an interconnected network providing physical, chemical and biological treatment to the flowing waste water. The following sections provide brief descriptions on these components.

Plants

Wetland plants (macrophytes) typically grow in water or soil media, subject to oxygen deficiency. The macrophytes employed in the constructed wetlands can be divided into four groups[6]:

- Emergent macrophytes. These are usually seen in water-saturated or submerged soil Examples include *Acorus calamus*, *Carex rostrata*, *Phragmites australis*, *Scirpus lacustris*, *Typha latifolia*. Oxygen is transferred from their roots into surrounding rhizosphere, to facilitate aerobic bacteria degradation[7].
- Floating leaved macrophytes. These are rooted in submersed sediments with a water depth of 0.5m–3.0m, and have either floating or slightly aerial leaves. Examples include *Nymphaea odorata*, and *Nuphar lutea*.
- Submerged macrophytes. These have their photosynthetic tissue submersed by water, grow well in oxygenated water and are mainly used for polishing secondary treated waste water[7].
- Freely floating macrophytes. These float freely on surface water. These plants are capable of removing N and P by incorporating them into plant biomass, by nitrogen denitrification, and can also remove solids. Examples include: *Lemna minor*, *Spirodela polyrhiza*, *Eichhornia crassipes*.

Table 3 provides the characteristics of common aquatic plants of wetland systems. In WaterAid CPs where DWTS will be installed it is recommended to provide the following macrophytes:

Table 3: Commonly used aquatic plants in constructed wetlands.

Common and scientific names	Desirable temp. ˚C	Seed germination ˚C	Salinity tolerance ppt*	Optimal pH	Root penetration cm
Cattail (*Typha*)	10-30	12-24	30	4-10	30
Common Reed (*Phragmites*)	12-33	10-30	45	2-8	60
Rush (*Juncus*)	16-26	---	20	5-7.5	---
Bulrush (*Scirpus*)	16-27	---	20	4-9	76
Sedge (*Carex*)	14-32	---	---	5-7.5	---

*ppt= parts per thousand

Microorganisms

Constructed wetlands provide an ideal environment to support the growth of microorganisms, which break down waste water pollutants by biodegradation. Bacteria, fungi, and algae are the predominant microorganisms of wetlands.

Media

Wetland media play a critical role in pollutant removal from waste water, as the media provides attachment surfaces to microbial communities, and ingredients for bio-reactions. The nature of wetland media is also an important factor to determine environmental condition (such as redox potential), inside the wetland matrix. Gravel is the most common media employed in subsurface flow wetlands. Typical gravel sizes used in HSSF wetlands are: 3–6 mm, 5–10 mm, and 6–12 mm. The media depth in VSSF wetlands is often maintained around 0.7 m, whereas in HSSF systems such depth is maintained around 0.6 m. According to UK specification, the arrangement of gravel media (in VSSF wetlands) is given in Table 4.[8]

Table 4: Size of gravel beds used in VSSF wetlands.

Layer	Depth	Substrate size
Top layer	23cm	6mm washed pea gravel
	10cm	12mm round washed gravel
Bottom layer	15cm	30–60 mm round washed gravel

Apart from gravel, other types of media can also be used in wetland systems to enhance pollutant removal mechanisms as per availability in local area.

Design factors

Waste water generation

Typical water consumption rate is considered to be 100L/person/day. For domestic purposes, waste water generation rate is around 80% of the consumed water. Waste water generation rate (i.e. flow rate) is calculated in terms of volume per day. Flow rate can be measured via: (a) employing a flow meter; (b) monitoring the rise of water level in a closed chamber for a specific time period; and (c) calculating the required time during initial filling of the first unit (of a treatment train) to overflow. It should be mentioned that design of a DWTS is dependent directly on the incoming flow rate; hence this parameter must be measured accurately.

Sludge production rate

Sludge production in DWTS systems (i.e. in septic tanks and ABR modules) is connected to organic material (BOD/COD) removal from waste water. Such organic removal occurs through aerobic and anaerobic processes; aerobic decomposition produces more sludge than does anaerobic degradation. For a DWTS treating domestic sewage, sludge retention period (inside a septic tank) is considered to be one year to allow anaerobic degradation. Desludging of the accumulated sludge is necessary for efficient performance. If sludge removal frequency is one year, then approximately 0.1L of sludge per person per day (0.1 L/P/d) may be considered as the generated sludge rate. If desludging intervals are greater than two years, sludge volume can be considered to be 0.08 L/P/d as sludge becomes compacted over this time span.

Area requirement

The area required by the typical four units of a DWTS is dependent on waste water volume. For 1m^3 of waste water, the required area has been illustrated in Table 5. Please note that Table 5 indicates a series arrangement of a vertical flow (VF) wetland (after an ABR) followed by a horizontal flow (HF) wetland (prior to a surface flow wetland). It should also be noted that integration of such hybrid wetland system (in a DWTS train) allows nitrification in the aerobic VF wetland, followed by denitrification in the latter anaerobic HF wetland. The last stage surface flow (SF) wetland can remove residual pollutants that are not removed by the previous units.

Table 5: Area requirement of different modules of a DWTS train, for 1m^3 of waste water.

Component	Minimum recommended area (m^2)
Septic tank	0.5
ABR	1.0
VF constructed wetland	3.75
HF constructed wetland	6.5
Polishing pond or SF wetland	1.2
Total area	**12.95 m^2**

Depending on waste water characteristics and land availability, a single VF or HF wetland can also be employed in a DWTS train, instead of a VF–HF hybrid system. In such cases, total area requirement employing a VF (Table 6) or a HF (Table 7) wetland will be lower when compared with Table 5 (employing combined VF-HF wetlands).

Table 6: Area requirement of a DWTS train with VF system as tertiary unit, for 1m^3 of waste water.

Component	Minimum recommended area (m^2)
Septic tank	0.5
ABR	1.0
VF constructed wetland	3.75
Polishing pond or SF wetland	1.2
Total area	**6.45m^2**

It should be mentioned that mathematical equations such as Kickuth equation or Monod kinetics combined with continuous stirred tank (CSTR) and/or plug flow pattern may calculate higher area requirements for VF/ HF wetlands, to provide treatment of waste water volume indicated in the Tables 5–7. As such, the proposed area values in Tables 5–7 are conservative, as these numbers have been estimated from practical experiences. It is recommended to provide greater area values (as indicated in the tables) for VF/HF systems, if sufficient land is available.

Table 7: Area requirement of a DWTS train with HF system as tertiary unit, for 1 m^3 of waste water.

Component	Minimum recommended area (m^2)
Septic tank	0.5
ABR	1.0
HF constructed wetland	6.5
Polishing pond or SF wetland	1.2
Total area	**9.2m^2**

Dimensions of the units

The septic tank should be rectangular in shape, with length and width ratio 3:1. All chambers should have equal depth; however, the depth of the first chamber can be deeper since most of the sludge accumulates in this zone.

For an ABR system, the hydraulic retention time (HRT) should be designed as one day (24 hours) to ensure 70–90% organic removal[4]. HRT can be calculated as the ratio of reactor volume and waste water generation rate. The upflow velocity should be ≤2m/hr.

The media depth of VF and HF wetlands should range between 1.0–2.0 m, and 0.9-1.5 m respectively. A clear space (30–40 cm) above the media should be provided to accommodate excess incoming flow (i.e. during rainy season). For VF and HF systems, greater depth and length should be provided respectively to increase the retention time of waste water inside the system, enhancing removal performances. The bottom slope of VF and HF systems should be 1%. Steeper slope will promote quick movement of waste water from inlet to outlet, resulting inadequate contact between plants, media, attached bacteria and waste water that may lead to inefficient treatment performances. Different types of media can be employed in wetland reactors. In DWTS wetland systems, special media, for example cupola slag (size 25–50 mm) can be employed, to enhance phosphorus removal. The chosen media should have a porosity ranging between 40–60%. For surface flow wetland, a shallow water depth between 0.5–0.6 m is recommended to maintain aerobic conditions.

Other design factors

For septic tanks, the inlet pipe can be placed either: (a) below the lowest scum level; or, (b) above water level to evacuate gas. The chambers should be designed to reduce turbulent flow, enhancing sedimentation of solids. The chambers should be water sealed. Manholes should be provided above each chamber for regular inspection and maintenance.

For ABR systems, the inlet pipes of every chamber should be placed at a certain height from the bottom (of the reactor). Such arrangement allows the mixing of the incoming waste water with the stored sludge to foster anaerobic degradation, due to presence of microbes inside the sludge mass. The chambers should be in series; the number of chambers is dependent on peak hourly flow of waste water. The last two chambers are often packed with media to allow solid filtration and biological degradation by attached growth process. Similar to septic tanks, the chambers of an ABR system must be water tight, with manholes above each chamber for maintenance purposes.

The inlet perforated pipe for a VF system should be placed parallel to the length of the bed, so that waste water can be distributed evenly over the media. Large stones may be placed on the top of the media to allow even distribution of waste water (inside the media), and to prevent clogging. The outlet valve is generally placed at the bottom of the bed; large stones are placed at the bottom to achieve homogenous waste water distribution towards the outlet. For HF systems, the inlet perforated pipe should be placed parallel to the width of the bed, above the inlet zone. Large stones should be placed in the inlet and outlet zones to prevent clogging. The outlet valve is placed at a certain distance (0.6–1.2 m) from the bottom of the reactor, to maintain constant water depth inside the media. The selected wetland site should not contaminate drinking water source. To achieve this objective, the bottom and side walls of the wetland systems should be sealed to avoid groundwater contamination. Different materials for example bricks, cement-sand plasters or low-density polyethylene sheets (LDPE) with a thickness ≥0.5 mm can be used. Polyethylene sheets should have root resistance properties; in addition these sheets should be UV resistant (if exposed to the sun). After sealing, leakage tests should be performed by filling the bed with water and be left overnight. If water loss is less than 2mm, sealing is considered to be satisfactory.

Box: Design of a DWTS for a residential building of 200 populations.

Step 1. Determine water consumption rate
Assuming typical water consumption rate to be 100L/P/d, total water consumption rate by 200 people can be calculated as: $200 \times 100 = 20000 L/d = 20 m^3/d$

Step 2. Determine waste water generation rate
Waste water generation is around 80% of the consumed water. As such, total waste water generation from the residential building can be calculated as:
$20000\, L/d \times 0.8 = 16000\, L/d = 16 m^3/d$

Step 3. Area of the septic tank and ABR for generated waste water
The area of the septic tank can be calculated as (Table 5): $16 \times 0.5 m^2 = 8 m^2$
From Table 5, the required area of the ABR can be calculated as: $16 \times 1.0 m^2 = 16 m^2$
To achieve 24 hrs retention time, the volume of the ABR unit can be calculated as: $Q \times t = 16 m^3/d \times 1d = 16 m^3$

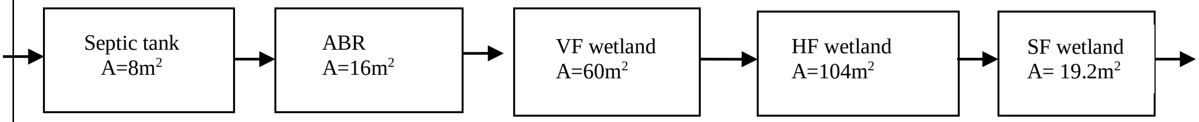
Step 4. Determine sludge generation rate
Approximately 0.1 L/P/d may be considered as the generated sludge rate, for desludging interval of one year. As such, sludge production volume can be calculated as:
$200 \times 0.1 L/P/d = 20 L/d$
Sludge production in a year can be calculated as: $20 L/d \times 365 d = 7300 L = 7.3 m^3$

Step 5. Calculating the area of the wetlands for generated waste water
From Table 5 the required area of VF, HF and SF wetlands can be calculated as:
Area of the VF wetland: $16 \times 3.75 m^2 = 60 m^2$
Area of the HF wetland: $16 \times 6.5 m^2 = 104 m^2$
Area of the SF wetland: $16 \times 1.2 m^2 = 19.2 m^2$

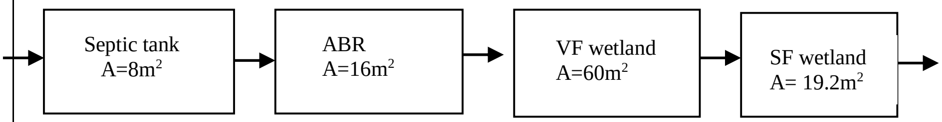
Step 6. Arrangement choices

The choice of the arrangements can be expanded between three options as illustrated below. Option A is the best choice for achieving better pollutant removal performances, due to sequential aerobic-anaerobic zones of VF and HF wetlands respectively. However, if sufficient land is not available for choosing option A, the engineer may restrict their choice between options B and C, depending on the influent waste water characteristics.

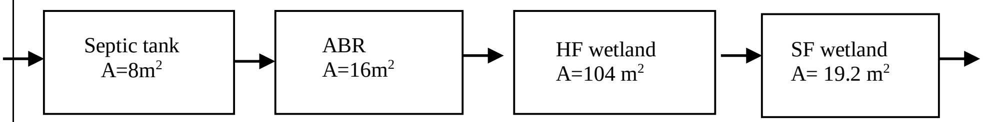
Option A: Total area requirement 207.2m²



Option B: Total area requirement 103.2m²



Option C: Total area requirement 147.2m²



Cost

Once the design engineer calculates all engineering measurements and decides what components the DWTS will comprise, the next step is to estimate the cost of the DWTS system. In most of the cases in developing countries, land availability is a major issue and the design engineer needs to optimise the final design considering both the project cost and land availability.

Filter media (brick chips, stones, gravel etc.) of the constructed wetland carries a big portion of the total cost of the DWTS system. Therefore, the design engineer needs to consider only locally available filter media in the constructed wetland. Brick chip is not recommended to use as filter media as it increases the operation and maintenance cost of the system. However, if stone chips or gravel are not possible to use, then over-burnt brick chips can be an alternate option as filter media. Table 8 shows the typical capital cost ranges while constructing DWTS in many of the developing countries in South Asia. However, since cost widely varies in other continents, particularly in Africa, it is always advisable to convert cost estimations based on local context.

Table 8: Capital cost of DWTS system for 1m^3 of waste water.

Component	Cost range (US$)
Settler	$20-25
ABR	$60-75
Constructed wetland	$200-300
Polishing pond or SF wetland	$70-75
Total cost	**$350-475**

Maintenance

The treatment performance of a DWTS can be enhanced by regular maintenance of DWTS modules. Such schedules can be divided into three categories: (a) general maintenance; (b) maintenance of settler and ABR; and (c) maintenance of constructed wetland systems.

General maintenance

General maintenance schedules include overall maintenance of the whole system, as illustrated below.

- Flow monitoring should be done during peak hours, when maximum waste water volumes are generated.
- A grease trap is required prior to the entrance of waste water into the settler unit. The grease trap should be cleaned twice in a month to prevent clogging. The pipes before and after the grease trap should also be cleaned regularly.
- A skimming process is required to remove oil and grease that float on the surface.
- The inlet and outlet pipes of all modules should be inspected monthly to prevent overflow/backflow into the treatment units.

Maintenance of settler and ABR

Maintenance schedules of settler and ABR units are summarised below:

- For the settler, desludging should be carried out yearly, or once in two years (depending on incoming waste water quality). For ABR unit desludging should be done after two to three years.
- During desludging from settler and ABR units, some sludge should be left inside the system for the continuation of biological removal mechanisms.
- After desludging, the removed sludge should be further treated prior to disposal.
- The filter materials of the ABR unit should be cleaned every five years to prevent clogging.

- Growth of plants around the settler and ABR units should be controlled to prevent the penetration of roots into pipes and chambers, which can damage structural configurations.

Maintenance of the wetland systems

The maintenance schedules of the wetland systems are listed below:

- The inlet structure should be designed in such a way so that it can distribute incoming flow homogeneously throughout the treatment zone.
- A drainage valve should be constructed at the bottom of the VF/HF wetlands to allow drainage of waste water (from the system) if required.
- For HF wetlands, macrophytes should be planted beneath the water table.
- After planting the wetland, the system should be waterlogged (with a mixture of waste water and fresh water), until the planted macrophytes are established. Such mixture will also promote the growth of bacteria inside the systems.
- Macrophytes should be harvested regularly to promote growth. Weak species should be removed from the system. Dry dead leaves need to be removed every two months. The grown macrophytes need to cut top off every six months.
- If clogging occurs, the wetland systems should be kept in resting mode (i.e. without dosing of waste water) for 21–30 days. After the specified time period, passing of waste water (from the previous treatment unit) can commence. However, if the resting period does not encounter clogging, the media should be cleaned and refilled into the wetland rectors.

Usually, such operation and maintenance works do not require full-time workers, but two man days for two workers are found to be effective for each episode of regular operation and maintenance work. Table 9 depicts typical operation and maintenance cost of a DWTS system in many of the developing countries in South Asia. Since, management modality varies a lot depending upon the community involved in different places, fixed staff salary is not considered in the presented O&M cost.

Table 9: Operation and maintenance cost of DWTS.

Activities	**Grease trap cleaning and scum removal** (collection pits)	**Plant management** (Dead leaf collection)	**Plant management** (Plant cut top off/ re-plantation)	**Filter media cleaning**
Interval	15 days	2 months	6 months	2 years
Yearly event (number)	24	6	2	0.5
Cost/year (US$)	$50–60	$35–40	$20–30	$175–200
			Total cost/year (US$)	**$280–330**

Reuse of waste water

Reuse of treated effluent (particularly treated domestic effluent) can reduce the pressure on fresh water sources (i.e. surface/ground water), as well as waste water discharge problems into the environment. Waste water reuse/recycling/reclamation can be an excellent option for a DWTS, as these systems are generally employed in decentralised areas (urban/rural), where sources of fresh water can be scarce.

Waste water reuse can be divided into two classes: indirect and direct reuse[9]. When water is extracted from lakes, rivers and aquifers containing sewage, it is termed as ‘indirect reuse’, while planned reuse of treated waste water for beneficial purposes is known as ’direct reuse’. There are many benefits of waste water reuse, including:[10]

- **Reduced costs***:* Recycled waste water can reduce pressure on municipal supplies, thereby saving drinking water used for such purposes.

- **Low environmental risks***:* Soil and plants can take up many contaminants (i.e. salts, nutrients and sediments) of the recycled waste water. As such, groundwater pollution due to the application of recycled waste water is minimal if proper waste water treatment technologies are employed.

- **Plant growth***:* Recycled waste water contains nutrients which can supplement the growth of plants, and help maintain soil fertility. The presence of nutrients in recycled waste water also reduces the necessity of artificial fertiliser addition.

Table 10 lists reuse categories and associated constraints. Subsequently, Table 11 illustrates the required guidelines for waste water reuse mostly used for professional purposes. WaterAid CPs can follow the guidelines of these recommended values after checking each country’s legal standards.

Table 10: Waste water reuse categories.[11]

Reuse categories	Constraints
Agricultural irrigation Crop irrigation, commercial nurseries	• Surface water and groundwater contamination if not managed properly. • Crops marketability, public acceptance. • Public health concerns due to presence of virus, bacteria and parasites.
Landscape irrigation Parks, school yards, golf courses, cemeteries, residential	• Effect of pathogens on public health.
Industrial Cooling water, boiler feed, process water	• Scaling, corrosion, biological growth, fouling. • Pathogen transmission in cooling water.

	• Cross-connection of potable and reclaimed water.
Groundwater recharge Groundwater replenishment	• Contamination of groundwater aquifer. • Organic chemicals in reclaimed water and their toxic effects. • Total dissolved solids, nitrates, pathogens in reclaimed water.
Recreational uses Habitat wetlands, lakes, ponds, marsh enhancement, fisheries, snow making	• Health concerns due to presence of bacteria, viruses. • Eutrophication due to presence of nutrients. • Toxicity to aquatic life.
Aquaculture	• Trace organics and their toxic impact. • Public acceptance.
Other uses Fire protection, air conditioning, toilet flush	• Public health concern by pathogens due to transmission by aerosols. • Scale corrosion and biological growth

Table 11: Waste water reclamation guidelines.[12]

Treatment level	Reuse types	Reclaimed waste water quality	Reclaimed waste water monitoring	Setback distances
Secondary[1] Filtration[2] Disinfection[3]	*Urban reuse* Landscape irrigation, vehicle washing, toilet flushing, fire protection, commercial air conditioners, and other uses with similar access or exposure to the water.	pH = 6–9 ≤10 mg/L biochemical oxygen demand (BOD) ≤ 2 turbidity units (NTU) No detectable fecal coliform/100 mL[4] 1 mg/L chlorine (Cl_2) residual (min.)	pH – weekly BOD – weekly Turbidity – continuous Coliform – daily Cl_2 residual – continuous	50 ft (15 m) to potable water supply wells
Secondary Disinfection	*Agricultural reuse for non-food crops* Pasture for milking animals, fodder, fibre and seed crops.	pH = 6–9 ≤ 30mg/L BOD ≤ 30mg/L total suspended solids (TSS) ≤ 200 fecal coliform/100mL[5] 1mg/L Cl_2 residual (min.)	pH – weekly BOD – weekly TSS – daily Coliform – daily Cl_2 residual – continuous	300 feet (90 m) to potable water supply wells
Site-specific	*Indirect potable reuse*	Site-specific	pH – daily	100ft (30m) to areas

Secondary and Disinfection (min.) May also need filtration and/or advanced waste water treatment	Groundwater recharge by spreading into potable aquifers.	Meet drinking water standards after percolation through vadose zone.	Turbidity – continuous Coliform – daily Cl_2 residual – continuous Drinking water standards– quarterly Other – depends on constituent	accessible to the public (if spray irrigation) site-specific

Notes

[1] Secondary treatment processes include activated sludge processes, trickling filters, rotating biological contactors, and many stabilisation pond systems. Secondary treatment should produce effluent in which both the BOD and TSS do not exceed 30mg/L.
[2] Filtration means passing the effluent through natural undisturbed soil or filter media such as sand and/or anthracite.
[3] Disinfection means the destruction, inactivation or removal of pathogenic microorganisms. It may be accomplished by chlorination, or other chemical disinfectants, UV radiation or other processes.
[4] The number of faecal coliform organisms should not exceed 14/100mL in any sample.
[5] The number of faecal coliform organisms should not exceed 800/100mL in any sample.

Conclusion

This guideline of DWTS has been prepared with the intention to bring science engineering into practice in the programmes of WaterAid CPs. The respective engineers/technical focal of each WaterAid CP is advised to follow the guideline considering local contexts of effluent discharge standards while implementing DWTS.

Overview of a DWTS, Bangladesh.

References

[1] Tchobanoglous G (1990). *Waste water Engineering*. Mcgraw-Hill College, November 1990.
[2] Saeed T, Al-Muyeed A and Ahmed T (2015). *Environmental Sanitation, Waste water Treatment and Disposal, 2nd ed*., 357. Available at https://goo.gl/tmuQLf
[3] BORDA (2009). *Decentralised Waste water Treatment Systems (DEWATS) and Sanitation in Developing Countries: a practical guide*, 36. Available at https://goo.gl/NyVEK3
[4] CSE (Center for Science and Environment) (2013). *Reinvent, Recycle, Reuse Toolkit on Decentralized Waste water Management*. Published by CSE, New Delhi 110 062, India.
[5] Vymazal J (2005). *Horizontal sub-surface flow and hybrid constructed wetland systems for waste water treatment*. Ecological Engineering, 25, 478-490.
[6] Williams LG (1964). *Relative strontium and calcium uptake by green algae*, Science, 146, 1488.
[7] Moshiri GA (1993). Constructed Wetlands for Water Quality Improvement. CRC press Inc.
[8] WRC (1996). *Reed Beds and Constructed Wetlands for Waste water Treatment*. Water Research Centre, Swindon, UK.
[9] WHO meeting of experts (1973). *Reuse of effluents: methods of waste water treatment and health safeguards*. World Health Organization, Tech. Rep. Ser. 517, Geneva.
[10] Madungwe E and Sakuringwa S (2007). *Greywater reuse: A strategy for water demand management in Harare?* Physics and Chemistry of the Earth, 32, 1231-1236.
[11] Tchobanoglous G and Angelakis A (1996). *Technologies for waste water treatment appropriate for reuse: Potential for applications in Greece*. Water Science and Technology, 33 (10–11), 15–24.
[12] U.S Environmental Protection Agency, US EPA (1992). *Manual- Guidelines for Water Reuse*, EPA/ 625/R-92/004, US Environmental protection agency, Washington DC, USA.