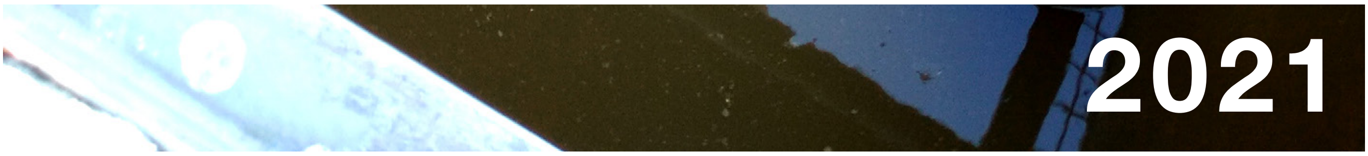
METHODOLOGIES & APPLICATION
FROM DOCUMENTED EXPERIENCE

# Comprehensive Overview on DEWATS Effluent Post-Treatments



## Comprehensive Overview on DEWATS Effluent Post-Treatments

is part of the series

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**MADE by UPM**

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The findings and conclusions contained within are those of the authors and do not necessarily reflect
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# Abbreviations & Acronyms

| | |
|---|---|
| **ABR** | Anaerobic Baffled Reactor |
| **AF** | Anaerobic Filter |
| **BMGF** | Bill & Melinda Gates Foundation |
| **BOD** | Biochemical Oxygen Demand |
| **BOD5** | Biochemical Oxygen Demand measured during 5 days at 20°C |
| **COD** | Chemical Oxygen Demand |
| **cm** | centimeters |
| **CW** | Constructed wetland |
| **°C** | Degree Celsius |
| **d** | day |
| **dia.** | diameter |
| **DEWATS** | Decentralised Wastewater Treatment System |
| **DPRK** | Democratic People's Republic of Korea |
| **EF** | Efficiency |
| **ELV** | Environmental Limit Values |
| **EPA** | Environmental Protection Agency (USA) |
| **g** | gramme |
| **h** | height |
| **HDPE** | High-Density Polyethylene |
| **HLR** | Hydraulic Loading Rate |
| **HRT** | Hydraulic Retention Time |
| **ISF** | Intermittent Sand Filter |
| **l** | liter |
| **L** | Length |
| **Log** | Logarithm |
| **m** | meter |
| **mm** | millimeter |
| **mg** | milligramme |
| **$m^2$** | square meter |
| **$m^3$** | cubic meter |
| **N** | Nitrogen |
| **N.A.** | Not available / Not applicable |
| **$N\text{-}NH_4$** | Ammonium Cation |
| **NPO** | Non Profit Organization |
| **$NO_3$** | Nitrate |
| **Nt** | Total nitrogen |
| **NTU** | Nephelometric Turbidity Unit |
| **OLR** | Organic Loading Rate |
| **O&M** | Operation and Maintenance |
| **P** | Phosphorus |
| **P.E.** | People-equivalent |
| **PGF** | Planted Gravel Filter |
| **PP** | Polypropylen |
| **Pt** | Phosphorus total |
| **PVC** | Polyvinyl Chloride |
| **rpm** | rounds per minute |
| **RSF** | Rapid Sand Filter |
| **SS** | Suspended Solids |

# Abbreviations & Acronyms

| | |
|---|---|
| **SSF** | Slow Sand Filter |
| **TF** | Trickling Filter |
| **TM** | Treatment Method |
| **TSS** | Total Suspended Solids |
| **T°** | Temperature as expressed in degrees |
| **UK** | United Kingdom |
| **USA** | United States of America |
| **UV** | Ultraviolet |
| **W** | Width |
| **WW** | Wastewater |
| **WWTP** | Wastewater Treatment Plant |
| ***** | Multiplication sign |
| **=** | Equal sign |
| **<** | Less-than sign |
| **>** | Greater-than sign |
| **^** | Exponent sign |

# Preface

This publication is the result of the technical assistance provided by UPM Umwelt-Projekt-Management GmbH (UPM) and its partners, the Centre for Sustainable and Ecological Sanitation (CSES) of the University of Science & Technology Beijing (USTB), and the Bureau of Socioeconomic Research and Training (BSERT) of the Bangladesh University of Agriculture (BAU) to the United Nations High Commissioner for Refugees (UNHCR), the Department of Public Health Engineering (DPHE) and the local WASH sector in Cox's Bazar, Bangladesh, in cooperation with the Bill & Melinda Gates Foundation.

The goal of this technical assistance assignment was to provide support to the emergency WASH sector and local sanitation administration, regarding faecal sludge management, with focus on value recovery in emergency settings, in order to sustainably improve the living conditions of displaced populations and their host communities.

The present manual "Comprehensive Overview on DEWATS Effluent Post-Treatments" was elaborated in the context of a series of training workshops organised by UPM and its partners in Cox's Bazar based on a Training Needs Assessment implemented in early 2019 among the local WASH community.

The content of this manual was presented as part of the Training session "DEWATS – Decentralized Wastewater Treatment Plant Systems, also applicable for treatment of faecal sludge" organized in Cox's Bazar in January 2020. The objectives of the training was to support trainees to gain understanding of the selection criteria for a decentralised wastewater treatment plant system chain, their limits and required adaptations to treat sludges and their appropriateness in the Rohingya Refugee camps context.

**OVERVIEW ON POST-TREATMENT TECHNOLOGY OPTIONS FOLLOWING AN ANAEROBIC DIGESTION SYSTEM**

# Introduction

Anaerobic systems make it possible to significantly reduce the levels of organic matter and settleable matter. In order to further purify effluents from anaerobic systems, it is recommended to apply aerobic systems. These can further reduce pollutants as well as pathogens and virus.

Several techniques suitable for refugee camps are explained in this Manual. The present chapter offers a brief overview on:

1

## Sand Filters

They are efficient in digesting remaining organic matter and reducing pathogens.

2

## Trickling Filters

They optimize the aerobic degradation of organic matter and have the additional advantage to occupy only very limited areas.

3

## Planted Filters

They reduce nitrogen concentrations to avoid the presence of nitrates in effluents and other nutrients; they also reduce pathogens.

4

## French Drains

They are recommended for post-treatment and infiltration in appropriate soils, topographically very flexible.

# Sand Filters

## Sand Filter Principles

→ Filtration through sand.

→ Aerobic digestion of organic matter and pathogens thanks to the biofilm (organic flocs) that develops in the sand.

## Rapid Sand Filter (RSF)

The rapid sand filter was first built in Sommerville, New Jersey, USA, 1885.

The rapid sand filter is only suitable for very diluted wastewaters or drinking water. It is a polishing technique to increase removal of BOD and suspended solids (or micro-algae). Rapid filtration is operated through coarse sand (0.6–2 mm) and a pump is required to overcome head losses and water head.

The filter works typically with an HLR (Hydraulic Loading Rate) less than 5 $m^3/m^2.h$.

Risk of clogging is high, depending on pre- and primary treatment; filter media can be cleaned by strong reverse flow and must be removed from the baffles and cleaned in case of clogging.

## Slow Sand Filter (SSF) or Intermittent Sand Filter (ISF)

The first documented use of sand filters to purify the water supply dates back to 1804. It was installed by the owner of a bleachery in Paisley, Scotland (UK), John Gibb. The same year, the first actual municipal water supply treatment plant designed by Robert Thom was also built in Scotland. The treatment was based on slow sand filtration.[1]

Slow Sand Filter is also called Intermittent Sand Filter or “infiltration-percolation” system.

The filtration is slow in fine sand. The wastewater (WW) rich in organic matter and air percolates in the sand layers. The important development of agglomerated bacteria, protozoa, etc. forming flocs is then observed on the sand particles and in the free spaces.

The technique allows a long and close contact between the flocs and the contaminants in the WW; this is very advanced aerobic digestion.

Because of accumulation of sludge on the surface, the distribution system and the sand top layer should be accessible for cleaning. Some authors recommend to put a rock layer (even covered with a geotextile) on the distribution pipes to avoid odors and hygienic risks.

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[1] Read more: https://www.lenntech.com/history-water-treatment.htm#ixzz6J2cxUmcv

# Example of Slow Sand Filter

Location : Ben Sergao, Morocco, 10,000 P.E.
WW daily flow : 750 $m^3$/d.

The wastewater treatment plant is composed of:

- 1 x 1,500 $m^3$ anaerobic settler (14 x 44 $m^2$ open basin);
- 1 x 250 $m^3$ buffer basin (filled 3 times per day);
- 5 x 1,500 $m^2$ sand filters.

All the components are fed by manual guillotine valves. Each day, three sand filters receive 250 $m^3$ of wastewater in the following pattern: Day 1 – filters Nº1, Nº2 and Nº3; Day 2: filters Nº2, Nº3 and Nº4, etc. ). Each sand filter works three days and is aerated or "breathes" three days (aeration).

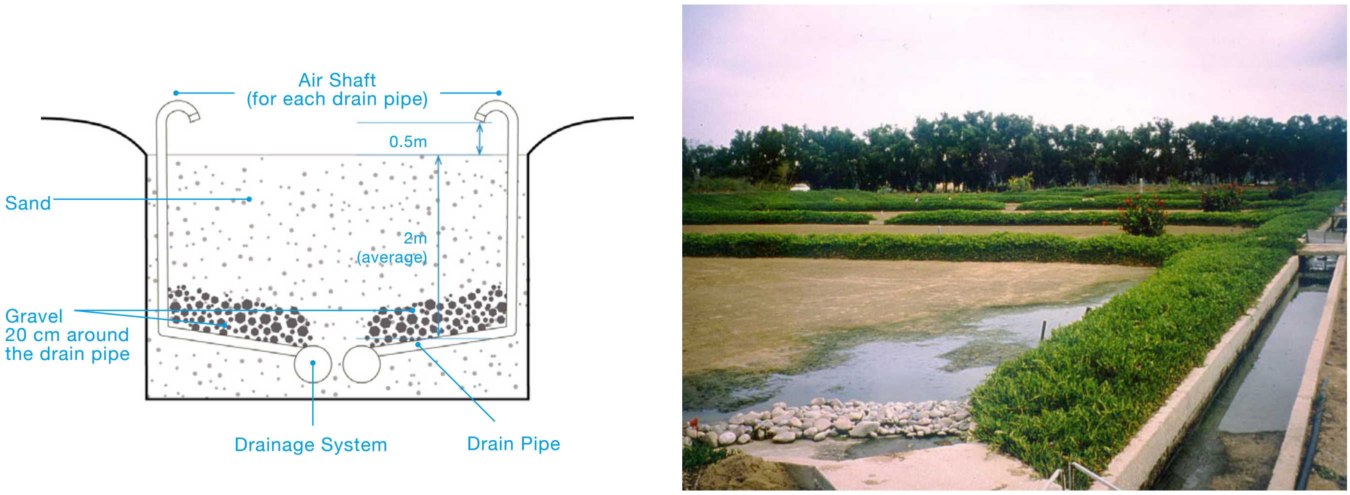

**FIGURE 1**: Slow Sand Filter in Ben Sergao, Morocco cross section (left) and view (right). [2]

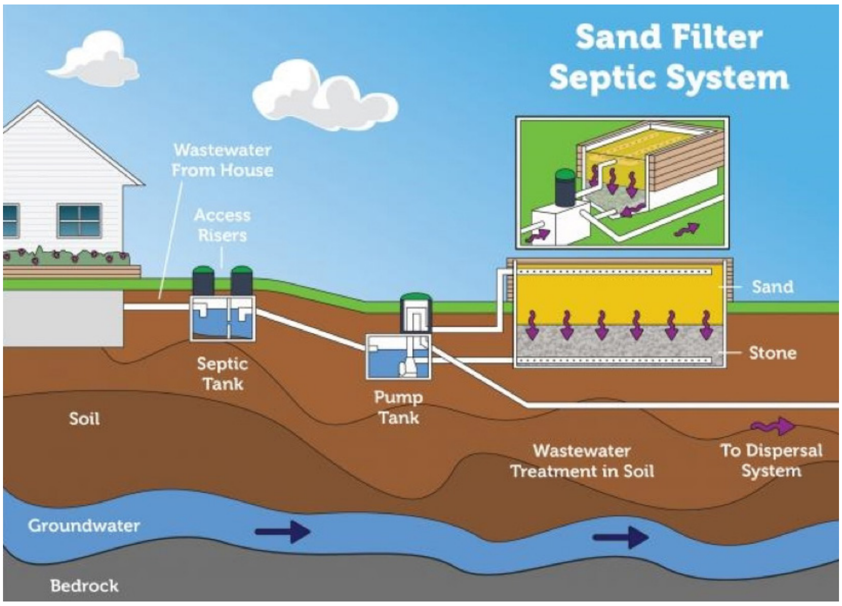

**FIGURE 2**: Sand filter septic system. [3]

[2] Source: Marc Wauthelet from RAMSA, Agadir, 1997.
[3] Source: https://www.epa.gov/sites/production/files/styles/large/public/2018-11/sand_filter_septic_system.jpg

# Trickling Filter

## Trickling Filter Principles

A Trickling Filter is characterized by:

→ Down-flow filtration through coarse filling material (fixed bed).

→ Aerobic digestion of organic matter thanks to the biofilm (organic flocs, 0.1–0.2 mm) that develops on the filling material.

→ The wastewater percolates down through the bed to a drain where it is collected and discharged or sent for further cleaning.

Three main working principles are applied as described in Figure 3:

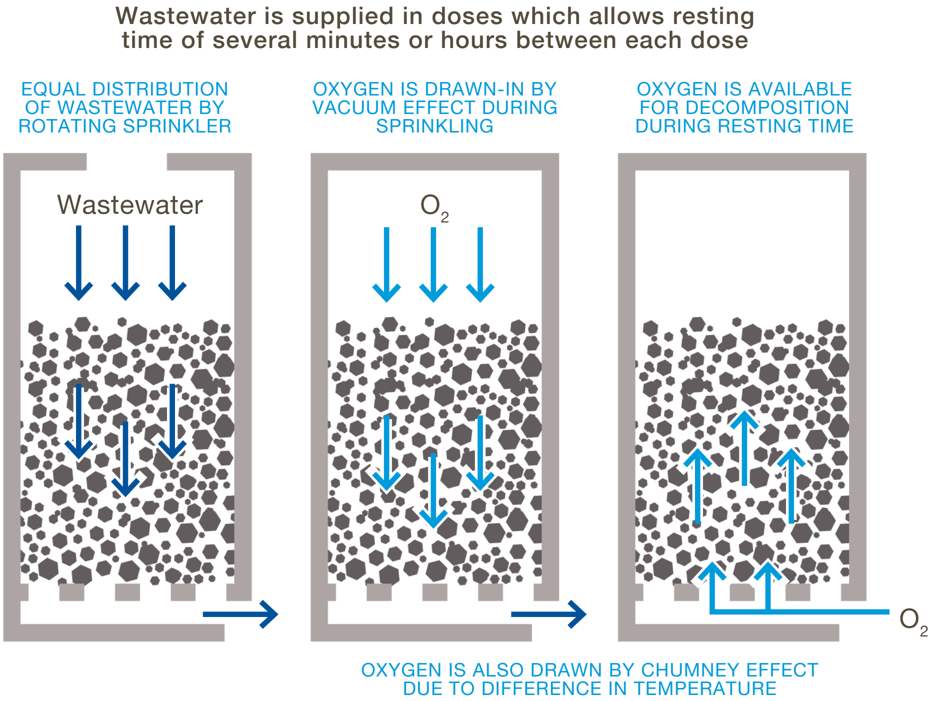

**FIGURE 3**: Principle of trickling filter.[4]

[4] Source: http://archive.sswm.info/sites/default/files/toolbox/SASSE%201998%20Trickling%20Filter.jpg

# Trickling Filter Technologies

## General remarks on the technology

- Old (> 100 years) and well-known. Trickling filters were first introduced in the USA in 1901 at Madison, Wisconsin.
- Appreciated as “Low-cost, low-maintenance, biological wastewater treatment”. “Trickling filters offer simple, reliable treatment in areas where large tracts of land are not available”.
- Good resistance to shock loadings.
- High design flexibility, able to handle a wide variability of wastewater strengths.
- Used to accelerate the development of bacteria, granulates (bacteria, algae, fungi, protozoa, ...) which will form “biofilms” on the filling material; good wastewater distribution, very porous media and aeration are essential.
- Big rainfalls will disturb the filter: during rainy season, a roof is necessary.
- Trickling filters generate sludge/light biofilms floating in the liquid effluent. Due to the “sloughing” mecanism, these suspended solids are difficult to settle and a lamellar clarifier or other post-treatment (sand filter, etc.) is required downstream of the filter.
- Sludge must be treated and disposed of.
- It also requires regular controls from an operator.
- The bed is commonly 2 to 3 m deep, held in place by a reinforced concrete basin with diameter up to 60 m and filled with rocks as filter media.
- Higher trickling filter is possible if plastic materials are used as media. The depth can then reach up to 10 m (“bio towers”).

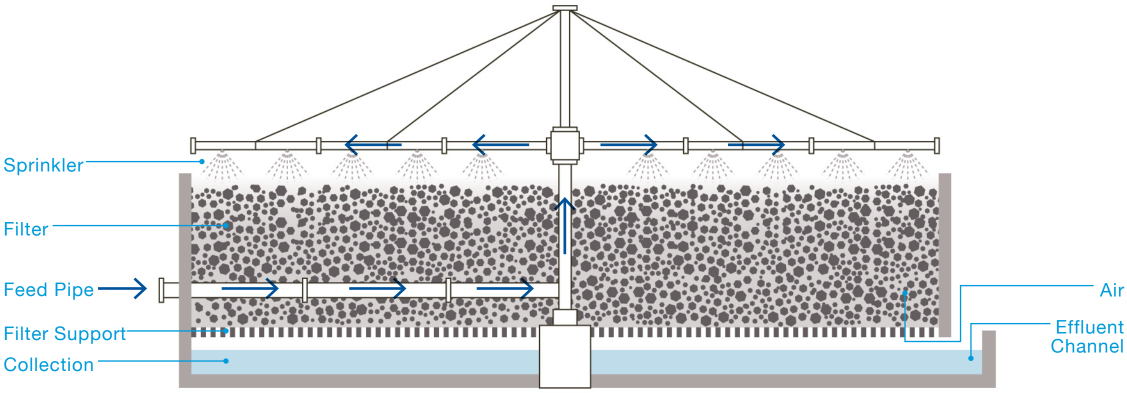

**FIGURE 4**: Sectional view of a trickling filter. [5]

[5] Source: Tilley. E. et al., EAWAG 2008.

## Filling media

- Filling material is rocks (dia. 5–8 cm), lava, gravels, small plastic tubes forming a bed in a (cylindrical or square) vertical tank.
- The filling media cannot contain toxic molecules (heavy metals, ...) which could impact the bacteria.
- Media with micro roughness accelerate the initial colonization.
- The porosity should be as high as possible: 95% for plastic material, max. 50% for gravels. Height is proportional to the porosity.
- Specific surface of the media must be higher than 200 $m^2/m^3$.
- Microbial growth will clog the filters if the filling material is composed of small pea gravel or other fine filtration material.
- Light plastic media (rings, balls, cut plastic bottles, etc.) allow high loading rates and taller filters that using smaller land area.
- The composition, size, uniformity and depth of the media are all affecting the performances.

# Trickling Filter Operation

## Wastewater distribution and quality

Wastewater has to be well distributed on the surface of the filter:

- By rotating (6 rpm) of perforated pipes on top of the cylindrical filter.
- By spraying through perforated pipes.
- The nozzles on the rotating arms must spray the wastewater evenly across the media.
- The technology is applied for pre-treated WW. It means at minimum a good pre-settling is required to avoid solid matters which cause clogging of the pipes and their holes.

## Aeration and temperature

Aeration and temperature are the main catalyzers of the biological aerobic digestion in the biofilm. Air comes passively from the top (down-flow aeration) and from the bottom (up-flow aeration through openings under the filtration bed).

Natural drafts are created by temperature differences between the outside air and air inside the filter. High WW temperature (more than 15°C) increases the performances of the process. The changes of temperature (seasonal) can accelerate the detachment of biofilms.

The trickling filter process is effective for removing suspended materials but is less effective for removing soluble organics. The BOD5 removal follows this equation: $k1 = k20 \, . \, 1{,}047^{(T-20)}$. It means that the performance increases by 4.7 % per °C.

## Problems

Disagreeable Odors

Ponding on Filter Media

Flies & Clogging

## Advantages & disadvantages [6]

**Advantages:**

- Simple, reliable, biological process.
- Suitable in areas where large tracts of land are not available for land intensive treatment systems.
- May qualify for equivalent secondary discharge standards.
- Effective in treating high concentrations of organics depending on the type of medium used.
- Appropriate for small- to medium-sized communities.
- Rapidly reduces soluble BOD5 in applied wastewater.
- Efficient nitrification units.
- Durable process elements.
- Low power requirements.
- Moderate level of skill and technical expertise needed to manage and operate the system.

**Disadvantages:**

- Additional treatment (nitrates reduction, etc.) may be needed to meet more stringent discharge standards.
- Possible accumulation of excess biomass that cannot retain an aerobic condition and can impair the TF performance.
- Requires regular operator attention.
- Incidence of clogging is relatively high.
- Requires low loadings depending on the medium.
- Flexibility and control are limited in comparison with activated-sludge processes.
- Vector and odor problems.

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[6] Source: Trickling Filters. https://www3.epa.gov/npdes/pubs/trickling_filter.pdf

## OVERVIEW ON POST TREATMENT TECHNOLOGY OPTIONS FOLLOWING AN ANAEROBIC DIGESTION SYSTEM

# Planted Gravel Filters

Planted gravel filters are also called:

- → Planted filter
- → Horizontal / Vertical filter
- → Horizontal Subsurface Flow Constructed Wetland
- → Treatment wetland
- → Constructed treatment wetland
- → Reed bed

Planted Gravel Filters (PGF) are known since the Romans who were using horizontal filters. It was mainly developed as constructed wetlands in the seventies in Germany, followed by USA, Denmark, England, France and Sweden. Currently, more than 50,000 PGF function in Germany and, at least, 8,000 in the USA. There is also a rapid development in Asia (China, India, ...). A PGF operates as secondary or tertiary treatment of wastewater downstream of a septic tank, digester or Anaerobic Baffled Reactor / Anaerobic Filter or Trickling Filter. Some models of vertical PGF can be fed directly with diluted wastewater. It reduces the pollutants (BOD, COD, SS, N, P) and pathogens.

Planted Gravel Filters exist in three main categories:

1. Free-Water Surface Constructed Wetland (CW) for tertiary treatment or treatment of storm water or diluted effluents.

2. Horizontal Filter for secondary and tertiary treatments of wastewater.

3. Vertical Filter for secondary and tertiary treatments of wastewater; “Pre-treatment” for horizontal filters.

# Free-Water Surface Constructed Wetland (CW) for Tertiary Treatment or Treatment of Storm Water or Diluted Effluents

**Advantages:**

- → At large sizes, it can give good results in terms of reduction of BOD, COD, SS.
- → It is easy to build and natural.

**Disadvantages:**

- → This model needs very large land areas (more than 10 m$^2$/People-Equivalent (P.E.)).
- → Exposed to air, the wastewater flow on the surface and problems of odors and insects occure.
- → Risk of contact of the wastewater with animals or people.
- → The reduction of pathogens is low.

# Horizontal Filter for Secondary & Tertiary Treatment of Wastewater

Subsurface flow constructed wetlands with sand filter bed have their origin in China and are mainly used in Asia.

**Advantages:**

- → The well-sized horizontal systems reduce efficiently the concentration of BOD, COD, SS, N and P. The pathogens concentrations are also strongly reduced.
- → The flow is a “Subsurface flow” under the surface of gravels.
- → There is no contact with animals or humans, and no odor.
- → It is natural and it produces biomass.
- → The system can be (semi-)continuously fed.

**Disadvantages:**

- → It requires relatively large land areas (3 to 5 m$^2$/PE) and it’s not so easy to size, to build and to clean.
- → Clogging occurs after 10 to 25 years.

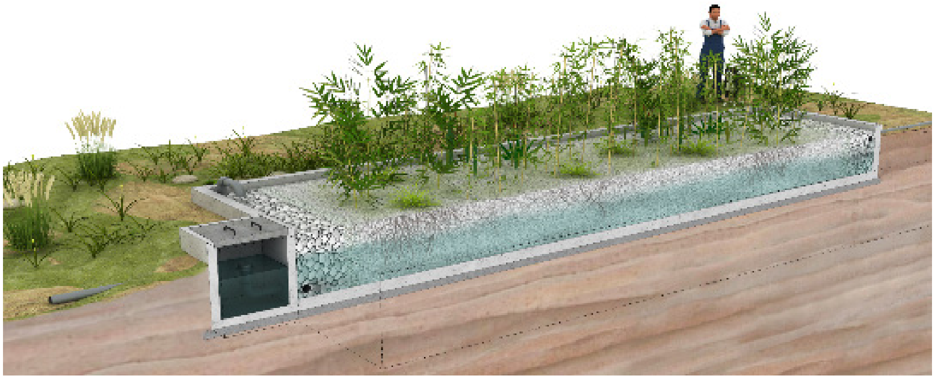

**FIGURE 5**: Horizontal filter with plants. [7]

[7] Source: Epuval NPO.

# Vertical Filter for Secondary & Tertiary Treatment of Wastewater; “Pre-Treatment” for Horizontal Filters

**Advantages:**

- → The vertical filters are efficient and reduce strongly the concentrations of BOD, COD, SS and pathogens.
- → It is natural and it produces biomass.
- → It can be fed with raw wastewater (with accumulation of sludge on the surface).
- → It requires only small land surface (1 to $2m^2$ / P.E.).

**Disadvantages:**

- → The reduction of N and P is low.
- → It needs high elevation (more than 1 m between inlet and outlet).
- → It is not easy to size, to build and to clean (when clogging).
- → There are risks of odors, insects and contacts with raw WW.
- → The vertical system is aerobic and must be then fed by batches (to allow aeration during rest period): it needs electric pumps or manual opening valves to feed multiple filters alternately.

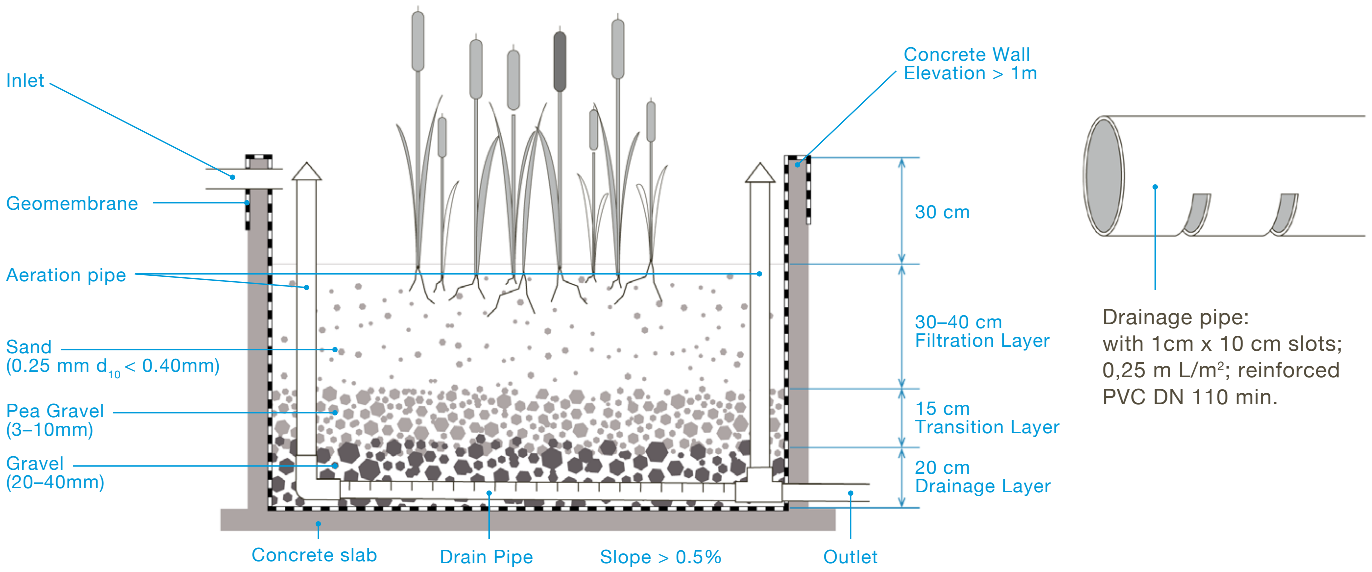

**FIGURE 6**: Sectional view of the vertical filter. [8]

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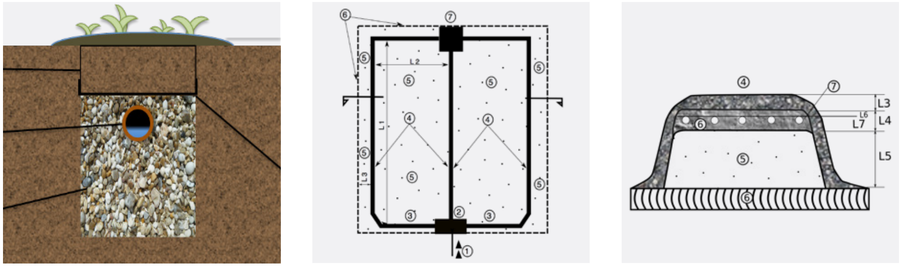
[8] Source: Epuval NPO.

# French Drains

## Description

The French drain first came into public eyes in the year 1859, when Mr. Henry French first published his book on farm drainage in Concord, Massachusetts, USA. A French drain is a flexible and effective way to deal with common water drainage problems. It consists of a sloping, gravel-filled trench with a perforated pipe at the bottom. French described how to use the drainage systems for jobs such as drying out swamps to create fields for growing crops. French drains have been used since then to solve drainage issues on residential and commercial properties as well. For some drainage problems, a French drain may be the best or only effective solution.

A French Drain is an option among several ex- and infiltration systems, as shown in Figure 7.



Infiltration Trenches
= French Drains

Infiltration Bed

Infiltration Mound

Sand Filter

Soak Pit: high risk of contamination of groundwater

**FIGURE 7**: Several options for infiltration systems.

A French drain is a draining method for treated wastewater in the natural soil. It can reduce pathogen caused health risks because there is no direct contact between human beings and wastewater. The pre-treated wastewater infiltrates into unsaturated soil; this improves the quality of wastewater treatment by activities of microorganisms.

Risks of pollution is high for shallow groundwater.[9]

[9] Source: Epuval NPO.

# Technology

In French drains, the infiltration must be slow and on a large area. Therefore, this technology is:

- → Not appropriate for sandy or gravel soils.
- → Not appropriate for non-porous soils like clay or rocks.
- → Not recommended for areas which should be used for vegetable gardening or construction.

It is used when there is no possibility of wastewater valorization.

The soils receiving the drains have to be sufficiently porous like silt or fine sands. The soils must have the capacity to filtrate and to be ‘biologically active’, i.e. hosting microorganisms for wastewater treatment. The spreading drain areas have to be adapted to the soil capacity; the daily flow must be infiltrated just within few hours. The drain trenches respecting slopes and perforations diameters must spread the wastewater on the entire area.

It should be avoided that the wastewater percolates already within the first meters of the piping system. The flow is unsaturated in the first soil decimeters. The microbial activities are high in this buffer zone. Below this buffer zone, the flow is saturated and continues to the groundwater.

It is recommended to place a pre-filter (200–500 l) upstream of the distribution chamber. This filter can stop debris or sludge and is a good indicator of the water quality.

# Operation & Mantainance

- → O&M workers need personal health protection equipment.
- → Operation consists of:
  - Check the components (pipes, chambers).
  - Clean the chambers (esp. distribution chamber).
  - Check if undisrupted wastewater is flowing in the pipes and drains.
  - Clean the soil from plastics, trees, ...
- → Check the upstream treatment, in case of clogging.
- → In case of clogged pipes:
  - Use a drain snake.
  - Replacement of the gravels/soil and drains.

# General Principles

Anaerobic systems make it possible to reduce significantly the levels of organic matter and settleable matter. In order to further purify their effluents from pollutants and pathogens, it is recommended to treat them with aerobic systems.

This chapter gives detailed presentation of sand filters. Slow or intermittent sand filters are efficient to reduce pathogens and organic matter remaining in the effluents from anaerobic systems. They therefore could play a prominent role in treating wastewater in refugee camps.

Sand filter processes are based on aerobic digestion. The air enters the filter bed from open surface or through aeration pipes ending under the sand. The commonly installed sand filter type works with intermittent load between two periods of aeration. This requires at least two sand filters to work alternately.

→ Filtration of wastewater through sand.

→ A biofilm of organic flocs develops in the sand.
This leads to aerobic digestion of organic matter, and pathogen reduction.

Each sand filter can be characterized by a curve linking the run length and the filter rate, as shown in Figure 8.

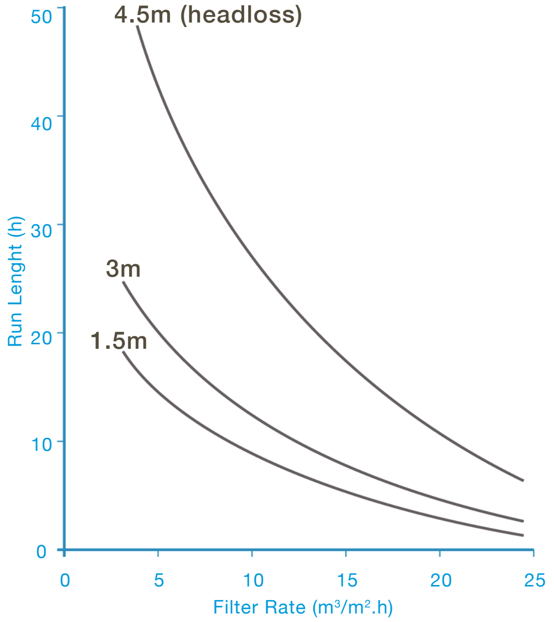


**FIGURE 8**: Curve linking run length and filter rate. [10]

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[10] Source: Adapted from EPA, 1975.

# Rapid Sand Filters (RSF)

Rapid Sand Filters (RSF) are suitable for treatment of highly diluted wastewater, and can also be used for purification of water for drinking purposes.

It is a polishing technique to increase the removal of BOD and suspended solids or algae. Rapid filtration is achieved through coarse sand (grain size: 0.6–2 mm). A pump is required to overcome head losses and water head.

RSF work typically with a Hydraulic Loading Rate (HLR) of less than 5m$^3$/m$^2$.h. There is a high risk of clogging, depending on pre- and primary treatments. In case of clogging, the filter media must be removed from the baffles and cleaned.

Clogging can occur after some days or even hours. It can be overcome by cleaning the filter with a reverse flow of water (backwashing), which fluidizes the filter bed.

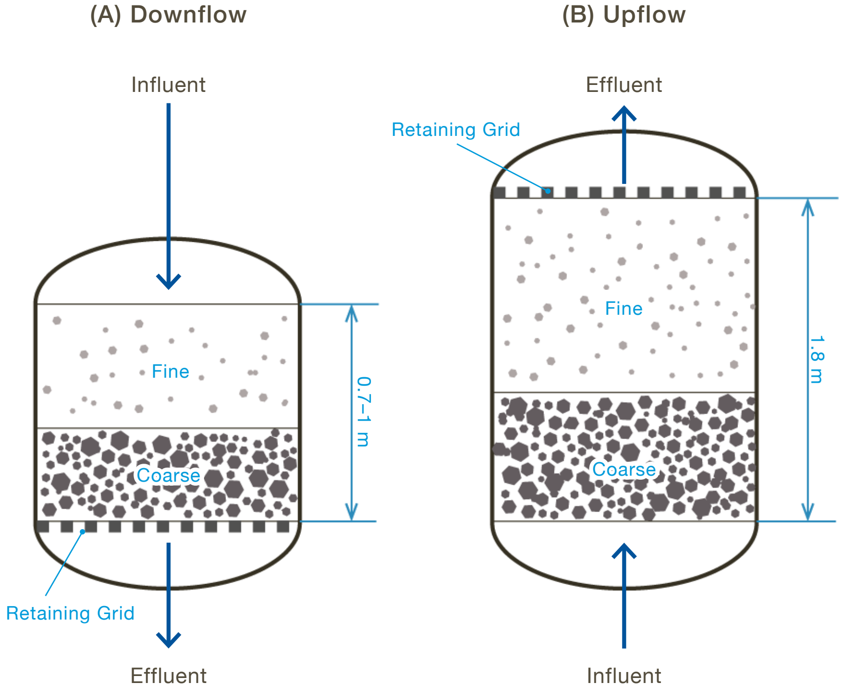

**FIGURE 9**: Main types of Rapid Sand Filters.

**SAND FILTERS**

# Slow Sand Filter (SSF) or Intermittent Sand Filter (ISF)

## Slow Sand Filters are also called Intermittent Sand Filters or “infiltration-percolation” systems.

In fine sand, infiltration happens slowly. Wastewater rich in organic matter and air percolates in the sand layers. A strong agglomeration of bacteria, fungi and protozoa develops, forming flocs on the sand particles and in the free spaces. This advanced aerobic digestion technique allows a long and close contact between the flocs and the pollutants in the wastewater.

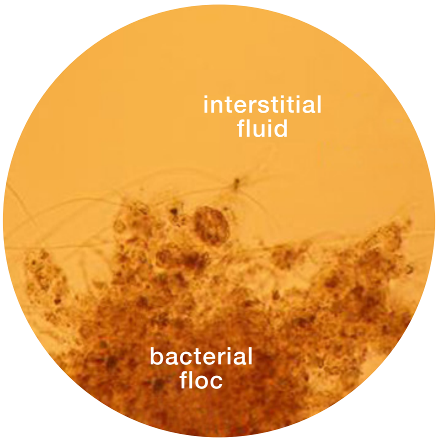

**FIGURE 10**: View of a floc in WW. [11]

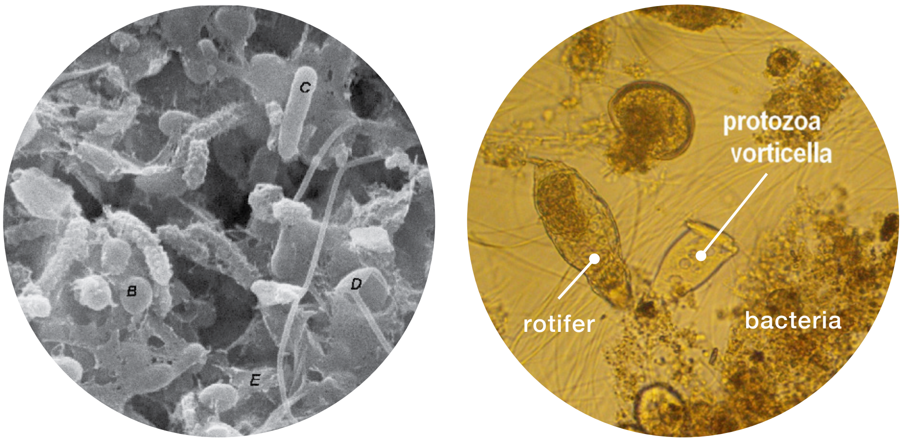

**FIGURE 11**: Micro-organisms in a slow sand filter media.[12]

The top layer of a sand filter is called “sludge blanket”, because it is always rich in micro-organisms. It has to be noted that, accumulation of sludge could provoke clogging of the sand surface. Therefore, operation and maintenance must include weekly raking and removal of surface sludge. After several months, new sand must be added on the surface to compensate for losses during scraping.

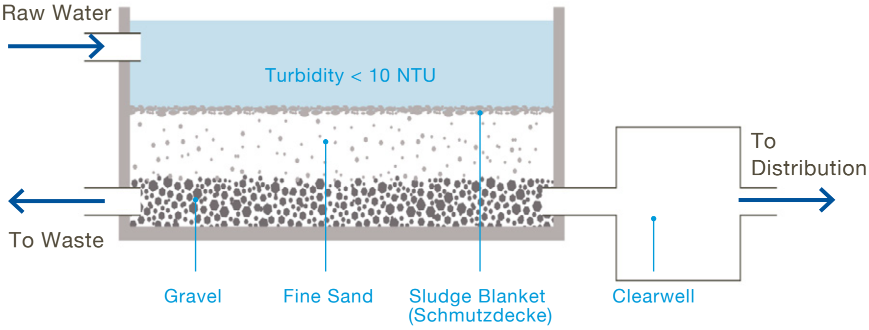

**FIGURE 12**: Slow Sand Filter. [13]

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[11] [12] Source: https://sti-biotechnologies-pedagogie.web.ac-grenoble.fr/content/elimination-du-carbone

[13] Source: American Water College.

# ISF Hydraulic Load Rate (HLR)

In literature, a wide range of hydraulic load rates is mentioned: The daily volume of wastewater per $m^2$ of a sand filter surface area varies between 22 to 400 l/$m^2$.d. In Morocco, small sand filters and sand filters for 10,000 and for 500,000 P.E. function best with a HLR of 83 to 100 l/$m^2$.d. [14]

As example, sand filters with slow flow into a sand surface were built after settlers, in Agadir, Morocco, to post-treat wastewater from 1,000,000 P.E.

**FIGURE 13**: **Wastewater treatment sand filter in Agadir, Morocco: views and plan.** [15]

# ISF Organic Load Rate (OLR)

In literature, a wide range of organic load rates (daily g BOD5 wastewater by $m^2$ of sand filter surface area) is available: from 2.5 to 360 g BOD5/$m^2$.d. However, based on experience in Morocco with small filters and sand filter for 10,000 and for 500,000 P.E., values from 2.5 to 10 g BOD5/$m^2$.d, or 19 to 25 g BOD5/$m^2$.d, respectively, are recommended.

# ISF Sand Quality

Sand quality is important for good functioning of the ISF. The sand must be washed until it is clean. The size of the round sand grains could vary between 0.1 to 1 mm. However, recommendations in literature highlight that best results are at 0.25, and up to a maximum of 1 mm. In sand filters constructed in Morocco, best results were achieved with grain sizes of 0.1 to 0.3 mm (d60).

The sand should not contain any limestone, organic matter, clay or other soil particles, and not more than 3% of fine particles.

# ISF Performances

In the USA, EPA reports BOD5 reduction from 160–297 mg BOD5/l (influent) to 2.2–3 mg BOD5/l (effluent). In Morocco, performances of ISF used as secondary treatment, directly after settling in anaerobic ponds, with HRT of 2 days resulted in BOD5 reductions from 505 (influent) to 52 (effluent) mg BOD5/L, and from 300 (influent) to 15 (effluent) mg BOD5/L.

# ISF Components

ISF is a down flow sand bed with:
- → Surface wastewater distribution.
- → Filtration in the porous sand layer.
- → Treated and filtered water drainage.
- → Watertight walls and bottoms
  —except in case of groundwater recharge.

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[14] From GIZ internal reports and presentations of Marc Wauthelet and RAMSA (Agadir).
[15] Source: Marc Wauthelet.

# ISF Wastewater Distribution

The surface distribution of wastewater can be done in several ways (See Figure 14):

- → Valve chambers: distribution filter by filter.
- → Perforated pipes on the surface of each filter.
- → Sprinklers, splash slabs.
- → Rapid flow: flow of some cm of wastewater within some minutes or even seconds.

It is not recommended to cover the perforated pipes with gravel, geotextile or soil. This can only be done for aesthetic or hygienic reasons (See Figures 15 & 16).

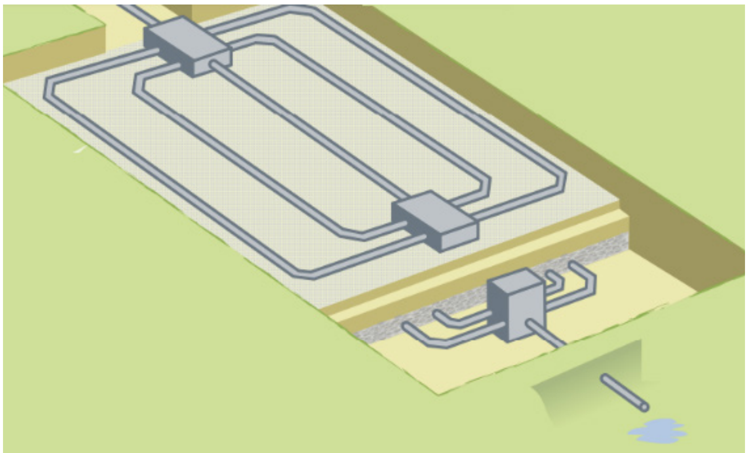

**FIGURE 14**: View of the sand filter fed by perforated pipes.[16]

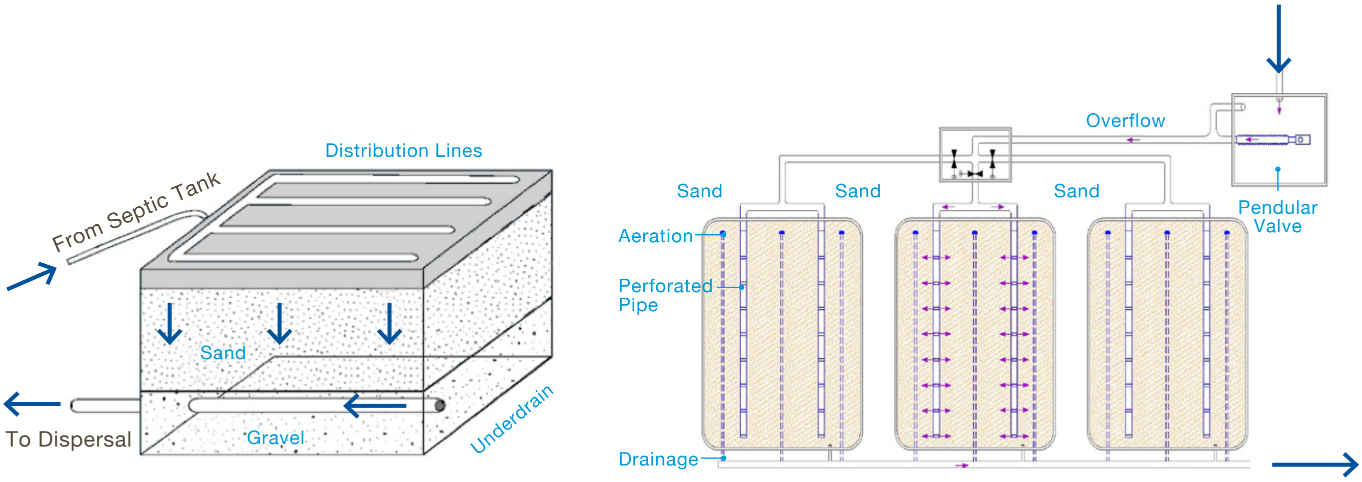

**FIGURE 15**: Sand filter fed by perforated pipes (center left) and three sand filters fed by perforated pipes and a pendular valve (center right).[17]

**FIGURE 16**: Sand filter fed by sprinklers (right).

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[16] Source: https://www.eau-rhin-meuse.fr/tlch/procedes_epuration/F09_infiltration_percolation.pdf

[17] Source: Agence de l'Eau RM, France.

For a good distribution of the wastewater on the surface, it is necessary to reach a high instantaneous flow by pre-storage of a dose in a tank with rapid openings, such as self-priming siphons and big valves (See Figure 17).

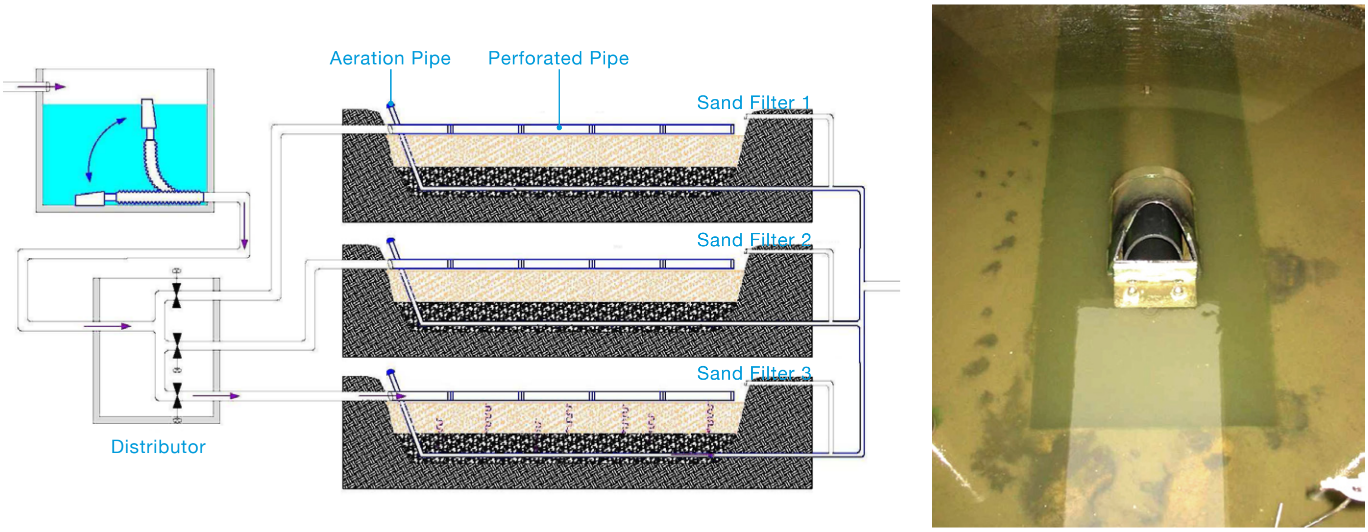

**FIGURE 17**: Pendular valve. [18]

Because of the accumulation of sludge on the surface, the distribution system and the sand top layer should be accessible for cleaning. Some authors recommend to put a rock layer (even covered with a geotextile) on the distribution pipes to avoid odors and hygienic risks.
It is important to take into account necessary cleanings, especially if wastewater is quite concentrated. Covering the sand top layer reduces also the aeration of the sand.

Figure 18 shows the distribution pipes in a rock layer. This rock layer has to be removed and cleaned when the filter is clogged.

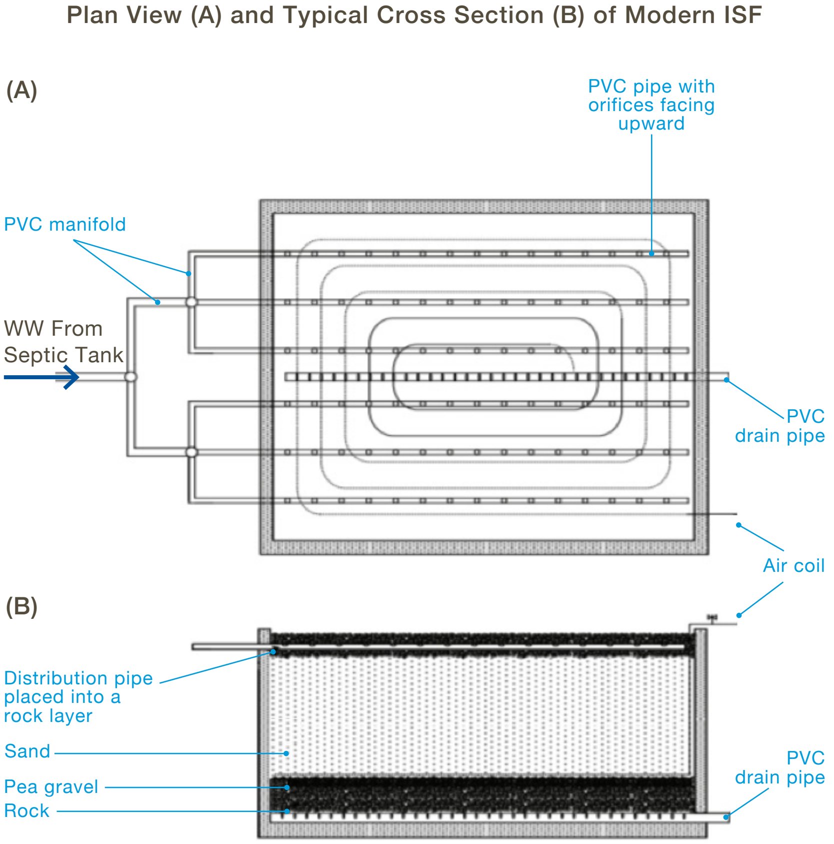

**FIGURE 18**: View of the simplified system with rock layers, one basin including two sand filters and one drain pipe. [19]

[18] Source: https://www.eau-rhin-meuse.fr/tlch/procedes_epuration/F09_infiltration_percolation.pdf
[19] Source: Curriculum on Low-Cost Wastewater Treatment, D. Xanthoulis

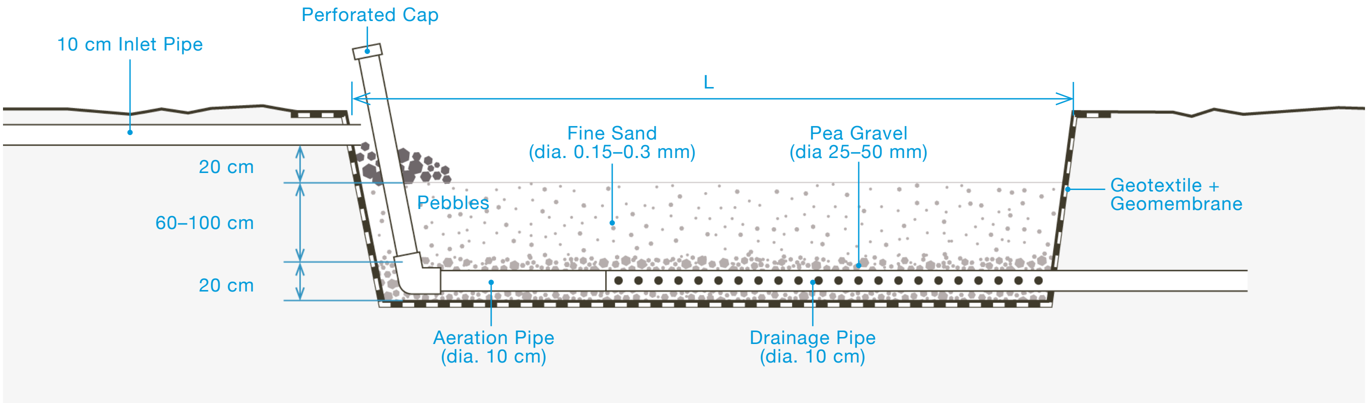

**FIGURE 19**: ISF longitudinal section; roof to be added before rain season. [20]

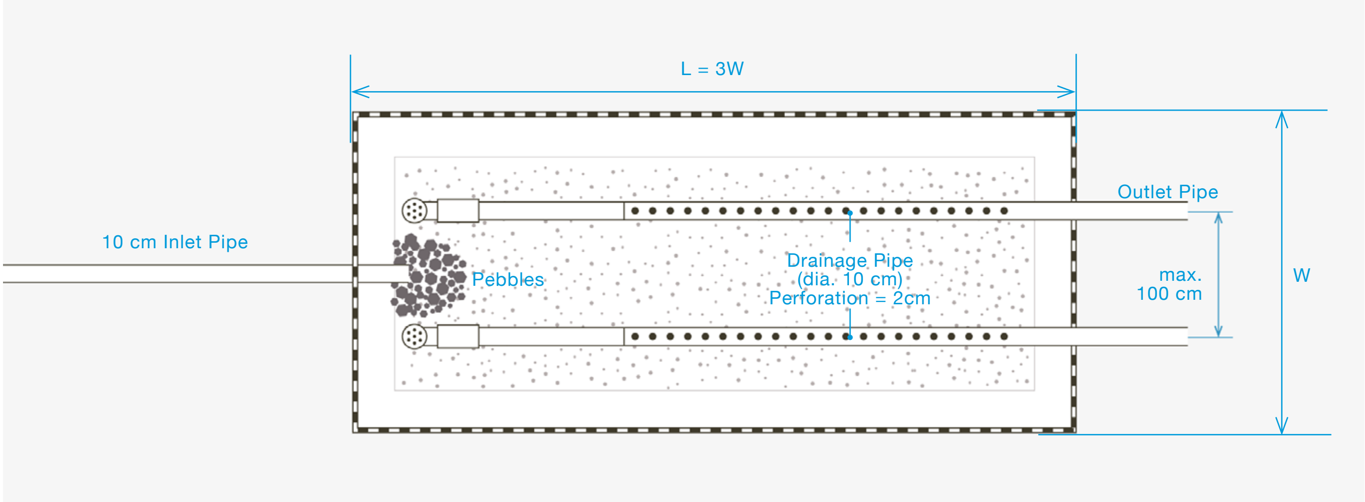

**FIGURE 20**: ISF plan view. [21]

# ISF Sizing

**TABLE 1:** Method to calculate the size of a sand filter: example.

Sand Filter

| Flow (F in $m^3$ WW/day) | Influent Concentration BOD5 (C in mg/l) | Area for Organic Load (Ao = F*C/20) | Area for Hydr. Load (Ah = F/0.1) | Area | Width (W = L/3) | Length (L) | Depth (Sand layer) |
|---|---|---|---|---|---|---|---|
| Data | Data | Calcul | Calcul | Chosen | Calcul | Calcul | Chosen |
| 10 | 300 | $m^2$ | $m^2$ | $m^2$ | m | m | m |
|  |  | 150 | 100 | 150 | 7.07 | 21.21 | 1.0 |
|  |  | Org. Load: 20 g BOD5/$m^2$.d max. | Recommended Hyd. Load: 0.1 $m^3/m^2$.d max. |  |  |  | 60–100 cm; 200 cm for disinfection |

[20] [21] Source: Marc Wauthelet, Epuval NPO.

# Example of Slow Sand Filter

Location : Ben Sergao, Morocco, 10,000 P.E.
WW daily flow : 750 m³/d.

The wastewater treatment plant is composed of:

- 1 x 1,500 m³ anaerobic settler (14 x 44 m² open basin);
- 1 x 250 m³ buffer basin (filled 3 times per day);
- 5 x 1,500 m² sand filters.

All the components are fed by manual guillotine valves. Each day, three sand filters receive 250 m³ of wastewater in the following pattern: Day 1 – filters N°1, N°2 and N°3; Day 2: filters N°2, N°3 and N°4, etc. ). Each sand filter works three days and is aerated or "breathes" three days (aeration).

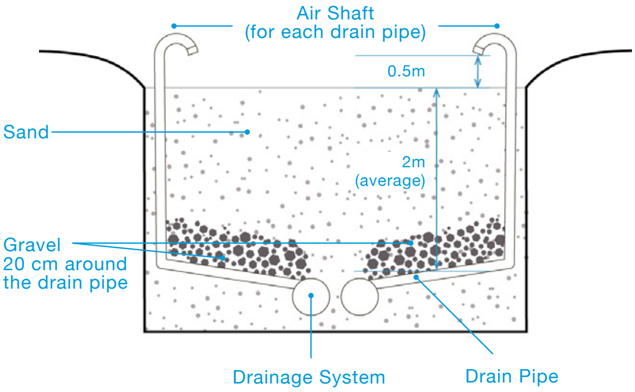

**FIGURE 21**: Slow Sand Filter in Ben Sergao, Morocco cross section (left) and view (right). [22]

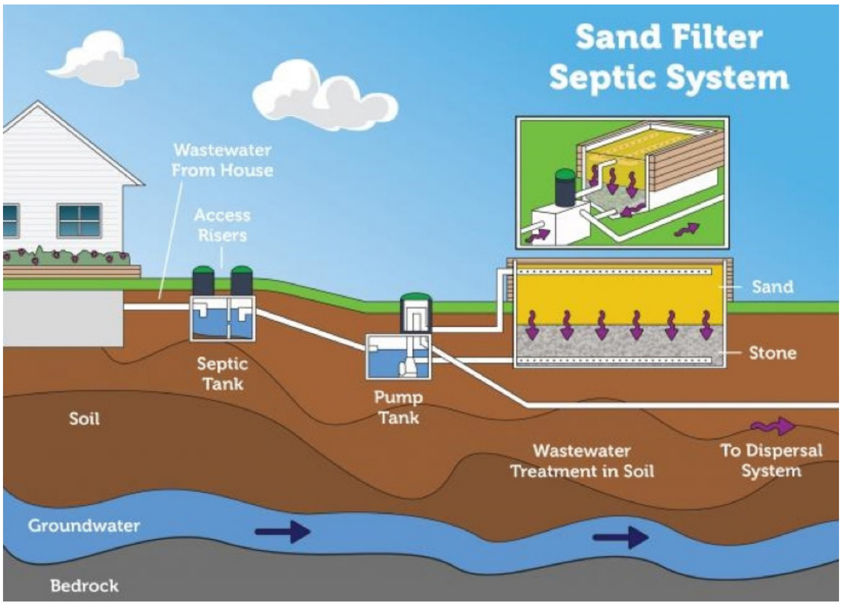

**FIGURE 22**: Sand filter septic system. [23]

[22] Source: Marc Wauthelet from RAMSA, Agadir, 1997.

[23] Source: https://www.epa.gov/sites/production/files/styles/large/public/2018-11/sand_filter_septic_system.jpg

# Test of a Small Sand Filter as Secondary Treatment

The tested sand filter has the following characteristics:

- Cylindrical.
- Concrete walls.
- 1.60 m diameter (2 m²).
- 0.2 m pea gravel + 1.50 m sand.
- Ambient temperature: 21°C.

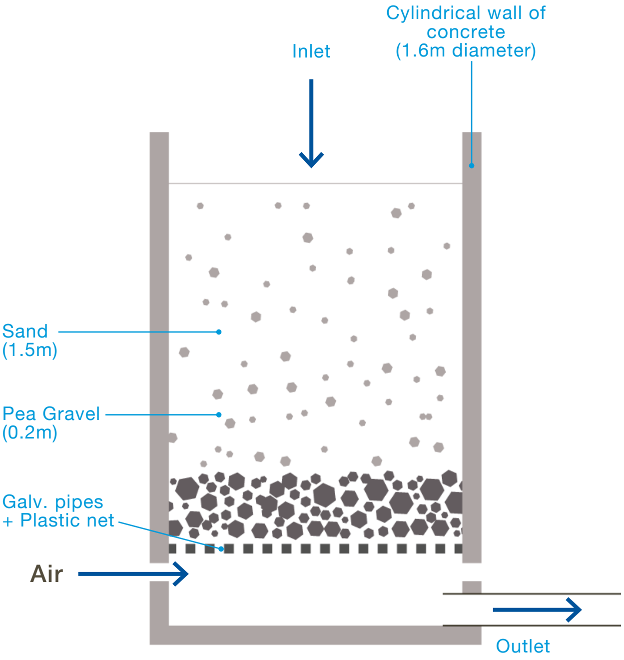

**FIGURE 23**: Test of a small sand filter as secondary treatment in a wastewater treatment plant, Ben Sergao, Morocco. [24]

During the test, feeding was done during 5d/w; the filter was left to rest 2d/w (weekends). The wastewater used for the test came from a trickling filter with a concentration of 36 mg BOD5/L. The applied Hydraulic Load Rate was 0.357 m³/ m².d.

The sand filter was the last component of a treatment chain consisting of settler and trickling filter. It is important to analyze the performance of a sand filter in terms of the removal of pathogens and helminth eggs. Each performance parameters were measured after each component, and are displayed in Table 3.

**TABLE 2:** Performances of a small sand filter as secondary treatment in a wastewater treatment plant, Ben Sergao, Morocco. [25]

| TSS | | COD | | BOD5 | |
|---|---|---|---|---|---|
| In | Out | In | Out | In | Out |
| 23.5 mg/l | 2.3 mg/l | 118 mg/l | 42.5 mg/l | 36.5 mg/l | 4.5 mg/l |

**TABLE 3:** Performance parameters of a treatment system composed by settler, trickling filter and sand filter.

| Performances % | Settler (2 d) | Trickling Filter | Sand Filter | Totally |
|---|---|---|---|---|
| TSS | 64.6 | 83.7 | 90.2 | 99.4 |
| COD | 52.6 | 76.8 | 64 | 96 |
| BOD5 | 56.4 | 79 | 87.7 | 98.9 |
| Eggs (/100 ml) | 47 | | | 0 |
| Coliforms (/100 ml) | $5.10^6$ | | | 170 |

[24] [25] Source: Marc Wauthelet.

**SAND FILTERS**

# Recommendations for Refugee Camps

① "… the surface layer of sludge should be raked and removed frequently"

- → Surface of the sand filter should be free, not covered by gravels, pipes, geotextile and similar material. A layer of pebbles is tolerated if there is a need to reduce odors and risks of contamination.

② "… the distribution of water on the filter surface must be uniform"

- → Rapid covering (tide) of the surface with some cm of WW.
- → To avoid hydraulic short circuits, the ratio of Length/Width = 3.

③ "… the sand must be aerated… aerobic treatment"

- → 2 or more parallel filters must be fed alternately. Rest periods must be observed between 2 feeds for sufficient aeration time.
- → Aeration through the surface and through pipes connected to the drainage.
- → Feeding with max. 0.1 $m^3/m^2.d$
- → No more than 20 g $BOD5/m^2.d$
- → Sand layer: 1 m (min.: 0.6 m) for COD/BOD reduction; >= 2 m for high reduction of pathogens.
- → Roof cover is necessary at least during the rainy season.
- → The biological active top layer is 10 to 50 c.

④ "… Sand must be clean, round, fine"

- → Use of washed sand with 0.15 – 0.3 mm diameter.
- → "Flow Buffer" made of pebbles in the wastewater inlet point to avoid sand erosion.

⑤ "… Drainage pipe with large perforations and protected from the sand entrance"

- → Drainage made with pipes (100 mm diameter) perforated each 10 cm with 2 cm holes or grinder slots.
- → Drainage pipes under a layer of pea gravel.

ISF is in general appropriate for a Refugee Camp

## TRICKLING FILTER

# Principles

Anaerobic systems make it possible to reduce significantly the levels of organic matter and settleable matter. In order to further purify their effluents from pollutants and pathogens, it is recommended to treat them with aerobic systems.

This chapter presents details on trickling filters. The trickling filters optimize the aerobic degradation of organic matter; they have the advantage of occupying only small areas

As explained earlier, a Trickling Filter is characterized by:

- → Down-flow filtration through coarse filling material (fixed bed).
- → Aerobic digestion of organic matter, thanks to the biofilm (organic flocs, 0.1– 0.2 mm) that develops on the filling material.
- → The wastewater percolates down through the bed to a drain where it is collected and discharged, or sent for further treatment.

Three main working principles are applied as described in Figure 24:

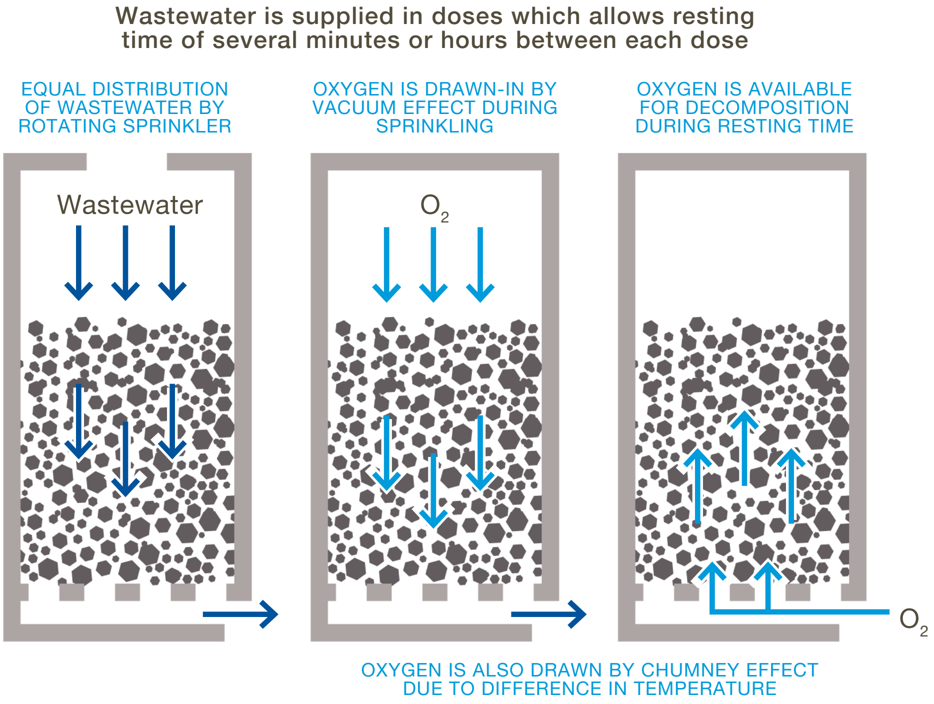

**FIGURE 24**: Principle of trickling filter. [26]

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[26] Source: http://archive.sswm.info/sites/default/files/toolbox/SASSE%201998%20Trickling%20Filter.jpg

Figure 25 illustrates the role of the bacteria fixed on a stone or brick. The bacterial growth forms biofilms on the surface of the filling material. When the biofilm becomes very thick, it falls off the supporting surface. The detachment of biofilms is continuous; the dropping off is called “sloughing”. A new development of biofilms will occur. Without the sloughing action, the media will clog and anaerobic conditions.

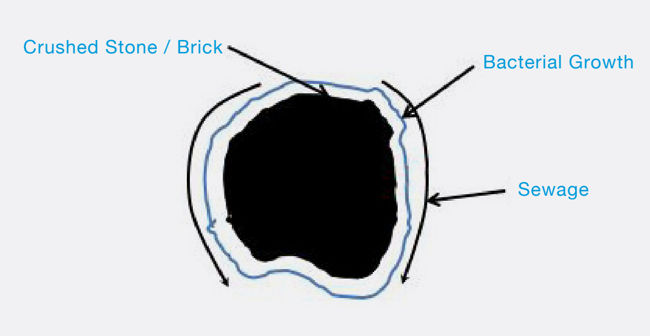


**FIGURE 25**: Organic removal process by bacteria fixed on a stone or a brick.

## TRICKLING FILTER

# Technology

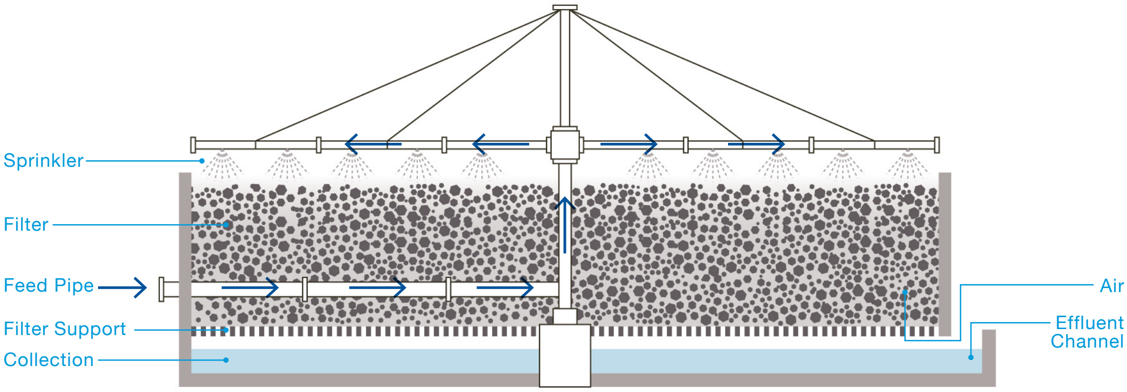
The trickling filter technology is more than 100 years old, and thus very well-known. Trickling filters are reputed to be low-cost. They require low-maintenance and provide biological wastewater treatment. Trickling filters offer reliable treatment in areas where large land areas are not available.

The technology offers good resistance to shock loadings. There is a high design flexibility, able to handle a wide variability of wastewater strengths. It is used to accelerate the development of bacteria, algae, fungi, protozoa, and further granulates which will form biofilms on the filling material. Good wastewater distribution, very porous media and aeration are essential. The filter bed is usually 2 to 3m deep, held together by a reinforced concrete basin with a diameter up to 60m. But much higher trickling filters, so-called bio-towers, are possible if light plastic tubes pieces (pipe cuts) are used. The height of such filter beds can then be up to 10m.

Trickling filters generate sludge and light biofilms floating on the liquid effluent. Due to the “sloughing” these suspended solids are difficult to settle. A lamellar clarifier or a post-treatment system, such as a sand filter, is required downstream of the filter.

They also require regular checks from an operator. Sludge must be treated and disposed of. Big rainfalls disturb the filter, therefore, a roof will be necessary during the rainy season.

**FIGURE 26**: Trickling filter building (above) and cross-section (below). [27]



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[27] Source: Tilley. E. et al., EAWAG 2008.

## TRICKLING FILTER

# Filling Media

Rocks with a diameter of 5–8 cm, lava, gravels, small plastic tube rings could be used to build up a filter bed in a vertical tank. This tank could be of any shape: cylindrical or square. The composition, size, uniformity and depth of the media are all affecting performances.

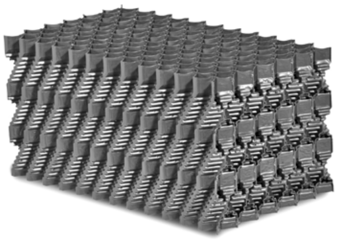
The porosity should be as high as possible: 95% for plastic material, max. 50% for gravels. Height is proportional to the porosity. Media with micro rough surface accelerates the initial bacterial and algal colonization.

Light plastic media (such as rings, balls, or cut plastic bottles) allow high loading rates and taller filters that use smaller land area. Specific surface of the media must be higher than 200 $m^2/m^3$. If the filling material is composed of small pea gravel or other fine filtration material, microbial growth would lead to filter clogging. In addition, it is important to make sure that the filling media does not contain toxic molecules such as heavy metals.

**FIGURE 27**: Example of a cylindrical trickling filter (left). [28]

**FIGURE 28**: Specific surface area of two different filling media (below).

**Plastic Ring Material**
Specific surface area
98~340$m^2/m^3$
POROSITY: 93%~95%



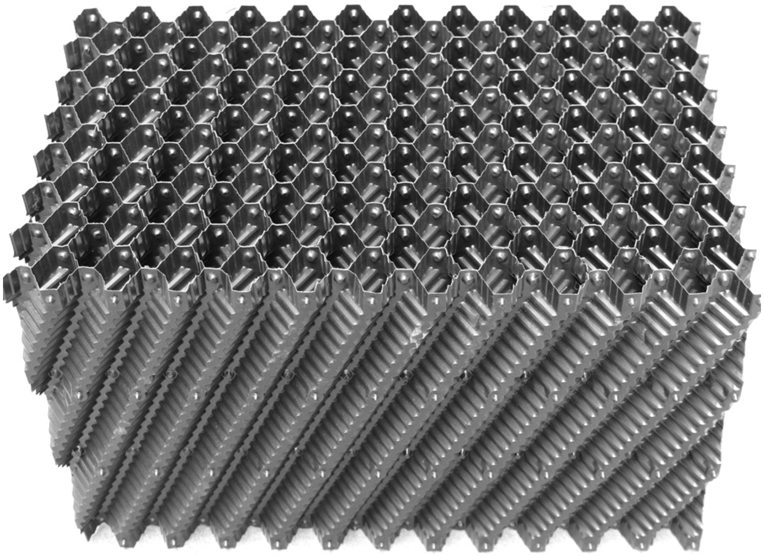
**Bellows-like Plastic Material**
Specific surface area
81~195$m^2/m^3$
POROSITY: 93%~95%

[28] Source: http://lele-ras-system.blogspot.com/2015/04/budidaya-ikan-sistem-resirkulasi.html

In small filter, inert media can be replaced by natural material like *Luffa Cylindrica*. After some months, this material must be removed and replaced. Natural filter material could be composted or treated before agricultural valorization.

**FIGURE 29**: *Luffa Cylindrica* as biofilm supporting medium (above).

**FIGURE 30**: Example of Plastic filling media (right).



**TRICKLING FILTER**

## Operation & Maintenance

A routine O&M schedule should be developed and followed for any trickling filter system. Follow the manufacturer's operation and maintenance instructions on pumps, bearings and motors.

Rotary distributors are very reliable and easy to maintain. A clearance of 15–25 cm is needed between the bottom of the distributor arm and the top of the medium bed to allow the wastewater from the nozzles to spread out and cover the bed uniformly.

# Wastewater Distribution and Quality

Wastewater has to be well distributed on the surface of the filter. This could be achieved by either rotating distribution pipes for a cylindrical filter (6 rpm), or by spraying through perforated pipes for a square filter. The nozzles on the rotating pipes must spray the wastewater evenly across the media.

In general, the technology is applied for pre-treated wastewater. That means at least a good pre-settling to avoid solid matters which could cause clogging of the pipes and the distribution holes.

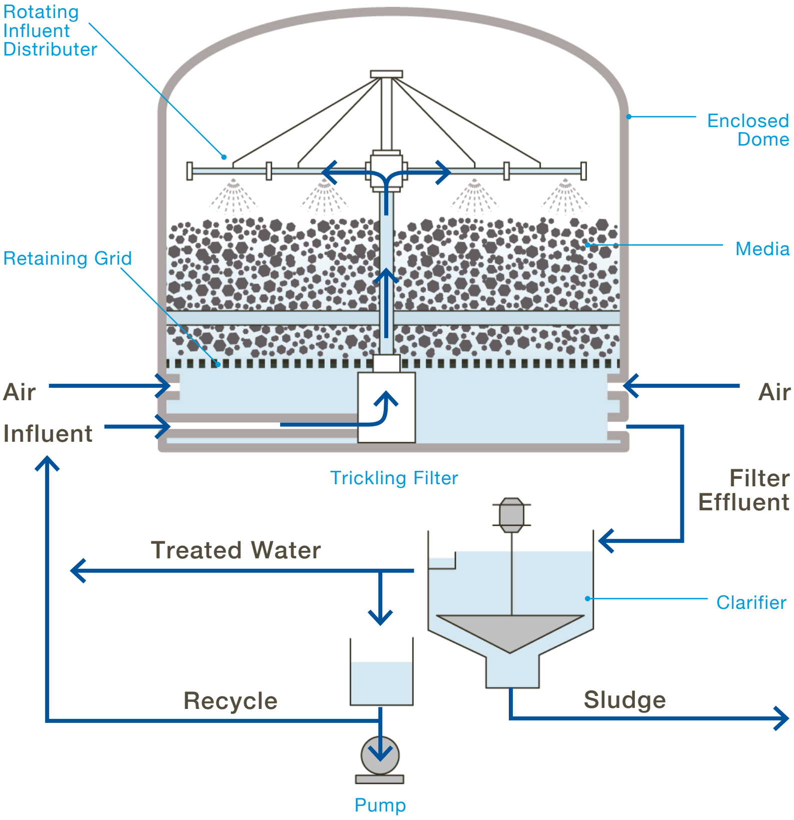


**FIGURE 31**: Trickling filter with rotating distributor, domed enclosure and effluent recycling. [29]

**FIGURE 32**: Rotating arms on a trickling filter (left) and fixed distribution pipes (right).

[29] Source: https://pt.slideshare.net/abhiiii4558/28737268-wastewatertreatmentppt/15

# Aeration and Temperature

Aeration and temperature are the main catalyzers of the biological aerobic digestion in the biofilm. Air comes passively from the top (down-flow aeration) and from the bottom (up-flow aeration) through openings under the filtration bed.

Natural drafts are created by temperature differences between the outside air and air inside the filter. High wastewater temperatures of more than 15°C, increase the performances of the process. The changes of temperature (seasonal) can accelerate the detachment of biofilms.

The trickling filter process is effective for removing suspended materials but is less effective for removing soluble organics. The BOD5 removal follows this equation: $k1 = k20 \,.\, 1{,}047^{(T-20)}$. It means that the performance increases by 4.7 % per °C.

# Problems and Remedies

**TABLE 4:** Trickling Filter: overview on possible problems and recommended solutions.

| Problem | Possible Reason | Solution |
|---|---|---|
| Disagreeable Odors | Excessive organic load causing anaerobic decomposition in filter. | • Reduce loading.<br>• Increase BOD removal in primary settling tanks;<br>• Enhance aerobic conditions in treatment units by adding chemical oxidants, pre-aerating, recycling plant effluent, or increasing air to aerated grit chambers; Scrub off gases.<br>• Use plastic media instead of rock. |
|  | Inadequate ventilation. | • Increase hydraulic loading to wash out excess biological growth.<br>• Remove debris from filter effluent channels, underdrains, and the top of filter media.<br>• Unclog vent pipes.<br>• Reduce hydraulic loading if underdrains are flooded; Install fans to induce draft through filter; check for filter plugging resulting from breakdown of the medium. |
| Ponding on Filter Media | Excessive biological growth or foreign matter in or on the filter. | • Reduce organic loading.<br>• Increase hydraulic loading to increase sloughing.<br>• Use high-pressure stream of water to flush filter surface.<br>• Maintain 1 to 2 mg/l residual chlorine on the filter for several hours.<br>• Flood filter for 24 hours.<br>• Shut down filter to dry out media; replace media if necessary.<br>• Remove debris. |

| Problem | | Possible Reason | Solution |
|---|---|---|---|
| Filter Flies (*Psychoids*)<br><br>In hot countries, there are risks of massive growth of worms, larvae and zoogloeal in the media.<br>A massive accumulation leads to reduction of performances up to complete clogging. Flies develop most when dry and wet conditions change constantly. More flies develop if the temperatures are higher than 15°C.<br><br>In cold countries or during cold seasons, the larvae of the butterfly mosquitoes (*Pythonidae*), roundworms and annelids, rotifers and protozoa develop much more slowly. These pests can be eliminated with chlorination, continuous feed (drowning), washing or use of insecticides.<br><br>A preventive measure is to cover the filter with a waterproof cover. Mosquito nets can be used on the aeration pipes or on the cover's windows. | | Inadequate filter media moisture. | • Increase hydraulic loading.<br>• Unplug spray orifices or nozzles.<br>• Use orifice opening at end of rotating distributor<br>• arms to spray filter walls.<br>• Flood filter for several hours each week during fly season.<br>• Maintain 1–2 mg/l residual chlorine on the filter for several hours. |
| | | Poor housekeeping. | • Mow area surrounding filter and remove weeds and shrubs. |
| Clogging | Icing Potential | Low temperature of wastewater. | • Use high-pressure stream of water to remove ice from orifices, nozzles, and distributor arms.<br>• Reduce number of filters in service as long as effluent limits can still be met.<br>• Reduce retention time in pretreatment and primary treatment units.<br>• Construct windbreak or covers. |
| | Rotating Distributor Slows Down or Stops | Insufficient flow to turn distributor. | • Increase hydraulic loading.<br>• Close reversing jets. |
| | | Clogged arms or orifices. | • Flush out arms by opening end plates.<br>• Remove solids from influent wastewater.<br>• Flush out orifices. |
| | | Clogged distributor arm vent pipe. | • Remove material from vent pipe by rodding or flushing.<br>• Remove solids from influent wastewater. |
| | | Distributor arms not level. | • Adjust guy wires at tie rods. |
| | | Distributor rods hitting media. | • Level media.<br>• Remove some media. |

### TRICKLING FILTER

# Advantages & Disadvantages[30]

**Advantages**

- → Reliable biological process.
- → Suitable in areas where large areas of land are not available for land intensive treatment systems.
- → May qualify for equivalent secondary discharge standards.
- → Effective in treating high concentrations of organics depending on the type of medium used.
- → Appropriate for small- to medium-size communities.
- → Rapidly reduction of soluble BOD5 in wastewater.
- → Efficient nitrification units.
- → Durable process elements.
- → Low power requirements.
- → Moderate level of skill and technical expertise needed to manage and operate the system.

**Disadvantages**

- → Additional treatment may be needed to meet more stringent discharge standards.
- → Possible accumulation of excess biomass that cannot retain an aerobic condition and can impair TF performance.
- → Requires regular operator attention.
- → Incidence of clogging is relatively high.
- → Requires low loadings depending on the medium.
- → Flexibility and control are limited in comparison with activated-sludge processes.
- → Vector and odor problems.
- → Snail problems.

### TRICKLING FILTER

# Sizing and Performances

Calculation has been proposed by Schulze. It gives the BOD concentration in the trickling filter effluent taking into account influent BOD, media depth, hydraulic load and constants.

In this equation, the value of k and n determined by Schulze at 20°C were 0.69/d and 0.67, as shown in Figure 33.

**Schulze derived the following equation:**

$$\frac{S_e}{S_0} = e^{-kD/Q^n}$$

**where**

→ $S_e$ = BOD concentration of settled filter effluent, mg/l
→ $S_0$ = influent BOD concentration
→ $k$ = an experimentally determined rate constant
→ $D$ = packing depth, m
→ $Q$ = hydraulic application rate, $m^3/m^2d$
→ $n$ = constant, characteristic of packing used
→ $e$ = 2.71828

**FIGURE 33**: Schulze equation for the calculation of trickling filter size.

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[30] Source: https://www3.epa.gov/npdes/pubs/trickling_filter.pdf

In Germany, volume is limited to 0.4 kg BOD5/m$^3$.d (0.2 if denitrification). As secondary treatment, trickling filters with loading rates of 0.3 to 1 kg BOD5/m$^3$.d can produce effluents with 15 to 30 mg BOD5/l and 15 to 30 mg TSS/L. The volume organic load (expressed in kg BOD5/m$^3$.d) is more important than the area organic load (kg BOD5/m$^2$.d) because the performance increases with the biofilm area.

In several German towns [31], the volume organic load of 1 and 2 kg BOD5/m$^3$.d results in performances of 75 to 50 % BOD5 reduction, respectively. In Karlsruhe, Germany, a trickling filter with slag as filling material treats wastewater coming from an activated sludge treatment. The high Hydraulic Load Rates from 0.60m$^3$/m$^2$.h to 0.90m$^3$/m$^2$.h allow 49% COD reduction and 73% BOD5 reduction.

In Morocco, tests on a small trickling filter were carried out with pretreated wastewater with the following characterization: pH 7.2, T° 22°C, pre-treated in an anaerobic pond with HRT 2d, and concentration of 172mg BOD5/L. The filter had a volume of 9.5m$^3$ – 3m high and 2m diameter. It was built with bricks, stainless steel pipes, and plastic net.

The filter was filled with pipes like those used for installation of electric cables (diameter 25 mm) cut in 5cm pieces. It had a specific area of 250m$^2$/m$^3$ (200 is recommended in Germany). The up-flow wastewater sprinkler consisted of perforated stainless steel tubes (1”1/2) on the surface of the trickling filter. The holes in the tubes were of 4 to 5 mm diameter, located every 30 cm.

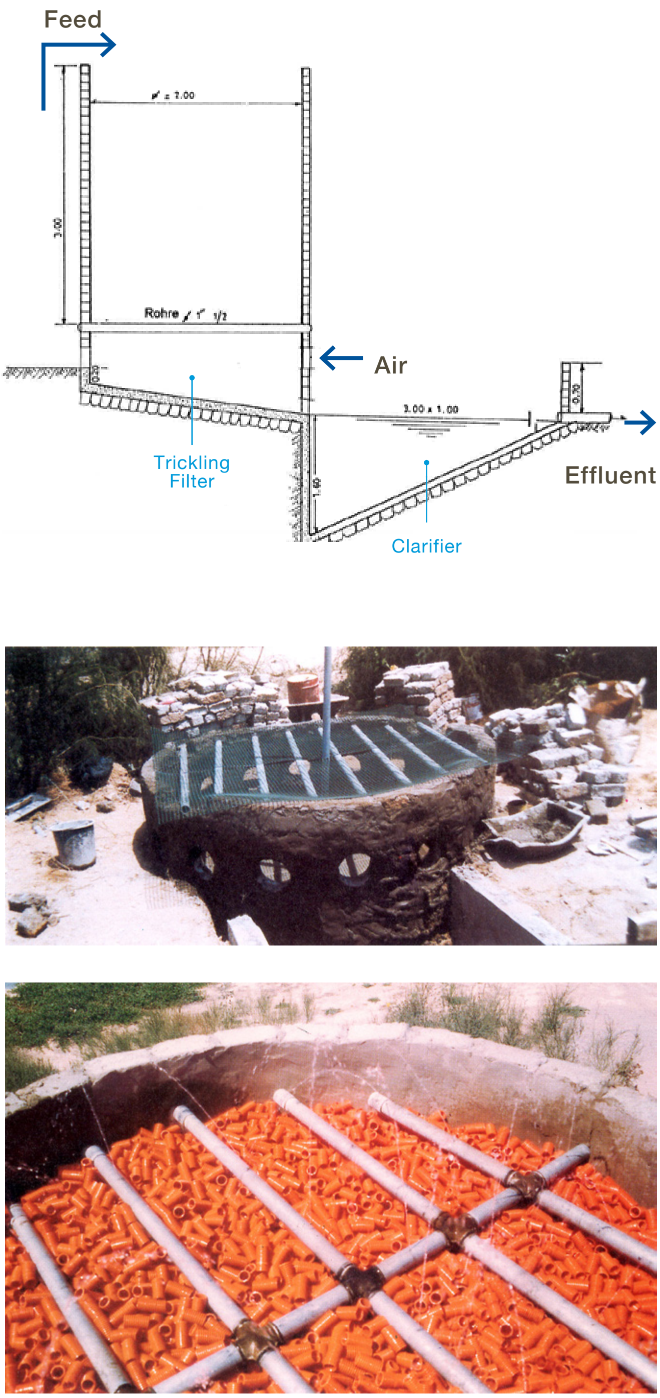

**FIGURE 34**: Plan and views of the drip body with secondary clarifier tested in Morocco. [32]

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[31] Nuremberg, Erlangen, Schwabach.

[32] Photos: Marc Wauthelet.

At low loads of 24 $m^3$/d (continuous flow, 320 P.E.) and 0.44 kg BOD5/ $m^3$.d (BOD5/$m^2$.d) or 0.32 m/h, the reductions were high:

| | |
|---|---|
| BOD5 in = 183 mg/l | COD in = 500 mg/l |
| BOD5 out = 19 mg/l | COD out = 58 mg/l |

Performances remain almost constant (+- 2%). There was no reduction of N, but high nitrification was observed. The suspended sludge was reduced at 83%.

With this low Hydraulic Load, there was no rinsing effect (accumulation of biofilms) and rapid development of larvae and worms was observed. Treatment through very high loads gave no results. Finally, the filter was cleaned with Hypochloride (bleach).

In a second test at 84 $m^3$/d (continuous flow, 1,120 P.E.), 1.53 kg BOD5/ $m^3$.d (BOD5/$m^2$.d) and 1.12m/h, the performance values were less:

| | |
|---|---|
| BOD5 in = 180 mg/l | COD in = 511 mg/l |
| BOD5 out = 35 mg/l | COD out = 118 mg/l |

Performances rates stay constant (+- 2%). No reduction of N and low nitrification were measured.

It means that the performance values were as follow:

At low loads : 88 – 90% (BOD5 – COD)
At high loads : 81 – 77% (BOD5 – COD)

In Jordan, trickling filters have good performances, as presented in Table 5. Other results are given in the Environmental Engineers Handbook, as in Table 6.

**TABLE 5:** Wastewater treatment plant removal efficiency of BOD5, COD and TSS for year 2005. [33]

| WWTP | TM | BOD5 | | | COD | | | TSS | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | In mg/l | Out mg/l | EF% | In mg/l | Out mg/l | EF% | In mg/l | Out mg/l | EF% |
| Baqa | TF | 965 | 41 | 95.75 | 2,247 | 110 | 95.11 | 930 | 46 | 95.05 |
| Karak | TF | 708 | 53 | 92.51 | 1,418 | 238 | 83.22 | 608 | 66 | 89.14 |
| | TF | 671 | 37 | 94.49 | 1,323 | 142 | 89.27 | 606 | 46 | 92.41 |

WWTP = Wastewater Treatment Plant; TM = Treatment Method; TF = Trickling Filter.

**TABLE 6:** Filter Type and BOD5 Removal (%). [34]

| Filter Type | BOD5 Removal (%) |
|---|---|
| Low Rate | 80 – 90 |
| Intermediate Rate | 50 – 70 |
| High Rate | 65 – 85 |
| Roughing Filter | 40 – 65 |

**TABLE 7:** Size calculation according to Schulze equation.

| Trickling FIlter | | | | | | |
|---|---|---|---|---|---|---|
| F = Flow ($m^3$ WW/d) | C = Influent Concentration BOD5 (mg/l) | T = Trickling Filter Capacity (T = F*C/400) | Area for Hyd. Load (P/1.2) | A = Area | D = Diameter (2+(A/π)^0.5) | H = Height (T/A) |
| Data | Data | Calculate | Calculate | Chosen | Calculate | Calculate |
| 10 | 600 | $m^3$ | $m^2$ | $m^2$ | m | m |
| h = Time of most waste water flow; data | P = max. peak flow in $m^3$/h (P=F/h) | 15 | 0.83 | 3 | 1.95 | 5.00 |
| 10 | 1 | OL = 400 g BOD5/$m^3$.d max. | Recommended Hyd. Load = 1.2 $m^3/m^2$.h max. (1.2 to 2) = 12 $m^3/m^2$.day in 10 hours feedings | | | |
| Name | Constant k | Packing depth (= H) | Hydraulic Rate (= F/A) | n, Constant | Se/S0 (Ratio effluent concentration / influent concentration) | Se = effluent concentration |
| Type | Constant | Chosen | Chosen | Constant | Calculate | Schulze Equation |
| Unit | d-1 | m | $m^3/m^2$/d | | Schulze Equation | mg/l |
| Values (Schulze) | 0.69 | 5.00 | 3.33 | 0.67 | 0.214 | 129 |

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[33] Source: https://www.susana.org/_resources/documents/default/3-3478-189-1542621713.pdf
[34] Source: Environmental Engineers Handbook, 1997.

**TRICKLING FILTER**

# Experience in a Refugee Camp in Lebanon

Temporary Informal Settlement Akkar District, Lebanon with 135 individuals. Grey water network set-up for 27 tents (600 m).

## 9 latrines connected to:

- → 3 x 3,000 l plastic septic tanks package (anoxic).
- → 3,000 l plastic tank (anaerobic) in line with receiving the grey water of 27 tents.
- → 10 m$^3$ plastic tank in line equipped with trickling filters (aerobic) and chimneys.
- → Soak away pit: infiltration of treated wastewater.

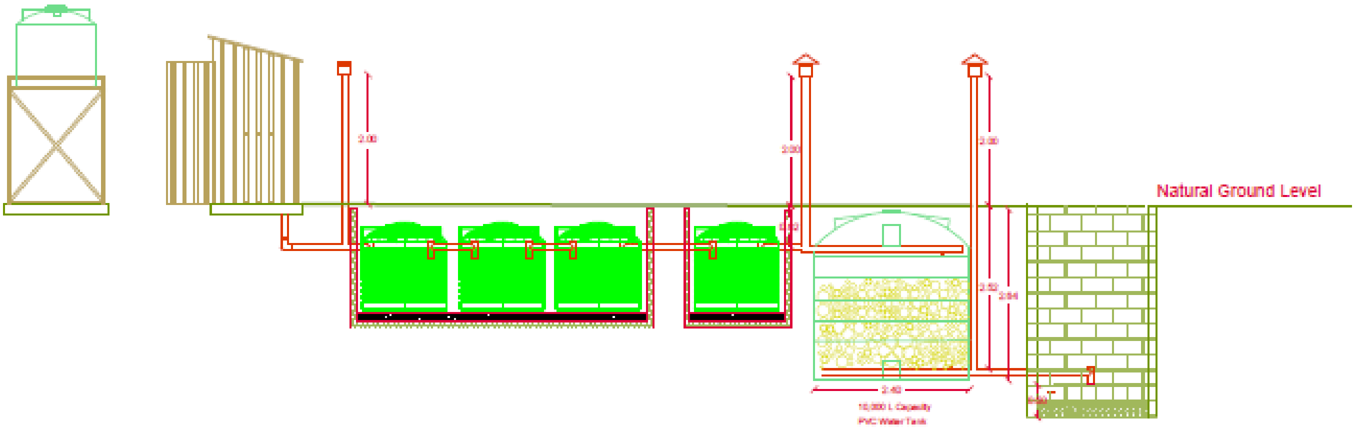

**FIGURE 35**: Underground trickling filter in refugee camp in Lebanon. [35]

## Performances

- → The system works with good results since 2.5 years.
- → High retention of solids into the tanks (90%): sludge volume reduction.
- → Still over the wastewater discharge Lebanese guidelines (ELV) = BOD5 25 mg/l.
- → Good reduction of BOD5: 84 % (from 785 to 125 mg/l).
- → Good reduction of E.coli: 94 %.

## Issues

- → Lack of efficiency with 1st results: Increase of ventilation (blower).
- → Still need improvement to respect Lebanese discharge guidelines:
  - Completes with humanitarian emergency rules.
  - On-going study regarding additional aerobic chamber.

[35] Source: Solidarité International.

## PLANTED GRAVEL FILTERS

# Introduction

Anaerobic systems make it possible to greatly and mainly reduce the levels of organic matter and settleable matter. In order to achieve greater purify, it is recommended to treat effluents from anaerobic systems with aerobic systems. They can further reduce pollutant levels, but also reduce pathogens.

Several techniques suitable for refugee camps are presented in this manual. Planted filters reduce nitrogen concentrations to avoid the presence of nitrates in effluents and other nutrients; they also reduce pathogens.

Planted Gravel Filters (PGF) are known since the Romans who used horizontal filters. They were mainly developed in the seventies in Germany, followed by USA, Denmark, England and France. Curerntly, more than 50,000 PGF function in Germany; and at least 8,000 in the USA. There is a rapid development in several Asian countries, such as China and India.

A PGF operates as secondary or tertiary treatment of wastewater downstream of a septic tank, biogas digester, Anaerobic Baffled Reactor, Anaerobic Filter or Trickling Filter. Some models of vertical PGF can be fed directly with diluted wastewater. PGFs reduce pollutants (BOD, COD, SS, N, P) and pathogens.

Planted gravel filters are also known as Planted Filter, Horizontal or Vertical Filter, Horizontal Subsurface Flow Constructed Wetland, Treatment Wetland, Constructed Treatment Wetland or Reed Bed.

Planted Gravel filters are mainly installed in the following three categories.

→ Free-Water Surface Constructed Wetland (CW)

→ Horizontal Filter

→ Vertical Filter

# Categories

## Free-Water Surface Constructed Wetland (CW)

A Free-Water Surface CW is applied as tertiary treatment or treatment of storm water, and for diluted effluents.

Its advantages: At large sizes, it can give good results in terms of reduction of BOD, COD, SS. It is easy to build and uses natural processes.

Its disadvantages: it needs very large land areas, more than 10 $m^2$ / P.E. Exposed to air, the wastewater flows on the surface, creating issues with insects and odors. The reduction of pathogens is low. In addition, humans and animals could come in contact with the wastewater. Therefore, this type of planted filter is not appropriate for refugee camps.

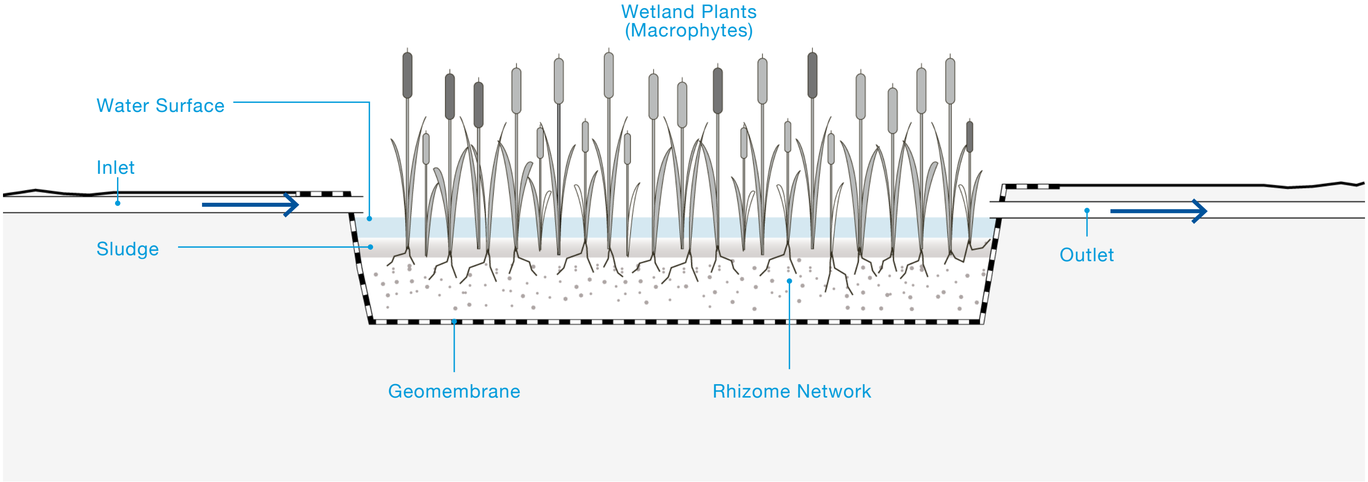

**FIGURE 36**: Cross-sectional view on a Free-Water Surface Constructed Wetland. [36]

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[36] Source: EAWAG Compendium.

# Horizontal Filter

## A Horizontal Filter serves for secondary and tertiary treatments of wastewater.

Its advantages: well-sized horizontal systems reduce efficiently the concentration of BOD, COD, SS, N and P. Pathogen concentrations are also strongly reduced. Thanks to the “subsurface flow”, under a layer of gravel, contact with humans and animals is not possible, and no odor occurs. It works with natural processes and produces biomass. The system can be (semi-)continuously fed.

Its disadvantages: the system requires relatively large land areas (3 to 5 $m^2$ / P.E.) and is not so easy to design, build and maintain. Clogging occurs after 10 to 25 years.

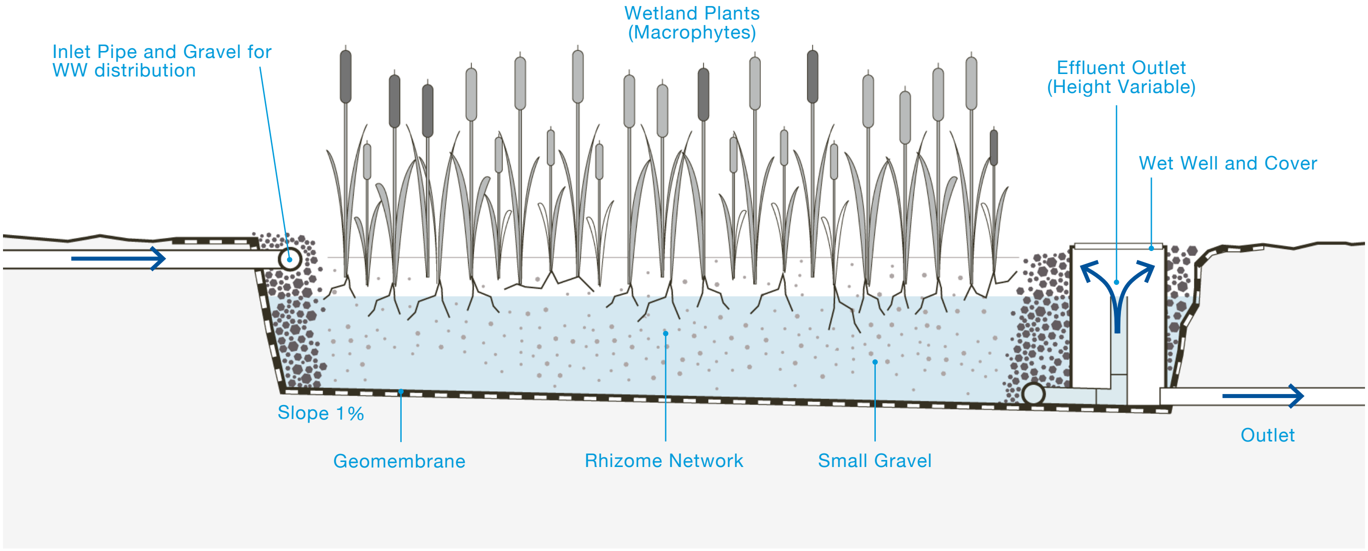

**FIGURE 37**: Cross-Sectional view on a Horizontal Filter. [37]

[37] Source: EAWAG Compendium.

# Vertical Filter

A Vertical Filter serves for secondary and tertiary treatment of wastewater, and as “pre-treatment” of wastewater before it enters a horizontal filter.

Its advantages: Vertical filters are efficient and reduce strongly the concentrations of BOD, COD, SS and pathogens. Its functions based on natural processes and the system produces biomass. It can be fed with raw wastewater, with accumulation of sludge on the surface. It requires only small land surface (1 to 2m$^2$ / P.E.).

Its disadvantages: Reduction of N and P is low. Only the Organic Nitrogen part is well oxidized and the produced $NO_3$- can be treated in a next treatment step (for example: horizontal filter).

It has to be built with significant height, because there must be more than 1 m height difference between inlet and outlet. It is therefore not easy to size it correctly and to clean the filter in the case of clogging. There are risks of odors, insects and contacts with raw wastewater.

The vertical system is aerobic and must be fed by batches to allow aeration during rest period. To feed multiple filters alternately, electrical pumps or manual valves must be installed to open and close the wastewater in- and out-flows.

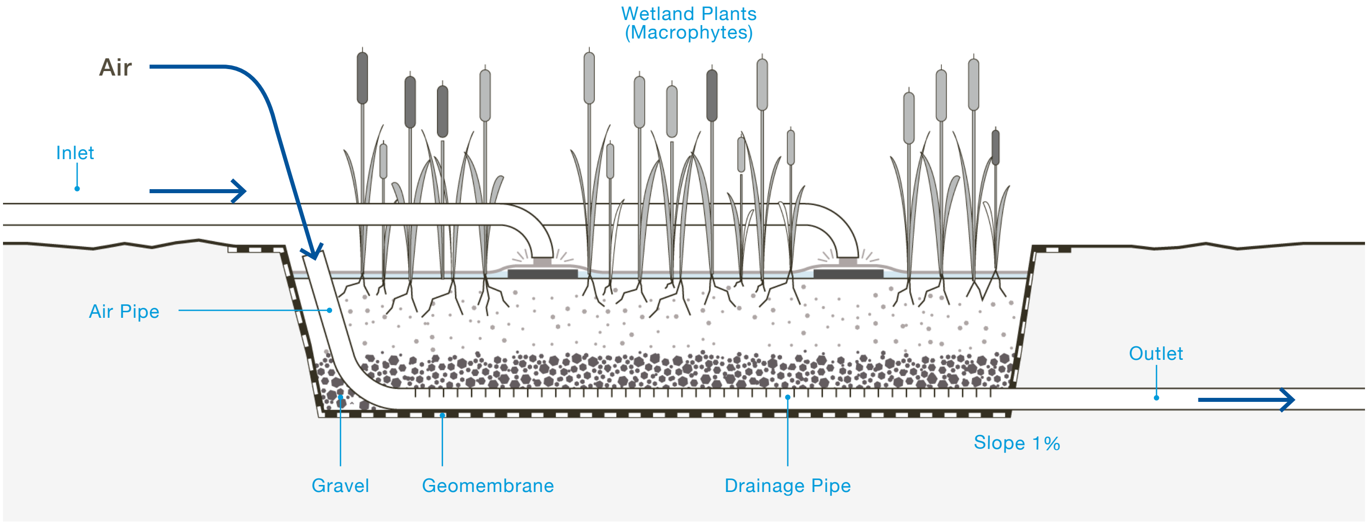

**FIGURE 38**: Cross-sectional view on a Vertical Filter. [38]

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[38] Source: EAWAG Compendium.

## PLANTED GRAVEL FILTERS

# Horizontal Filter

The horizontal filter needs a "pre-treatment / primary or secondary treatments" like septic tank or biogas settler (pre-treatment), or ABR/AF (as primary treatment), or a vertical filter bed (as secondary treatment).

These upstream techniques are useful to settle the sludge and to reduce the presence of organic matters (COD/BOD), greases, plastics and papers.

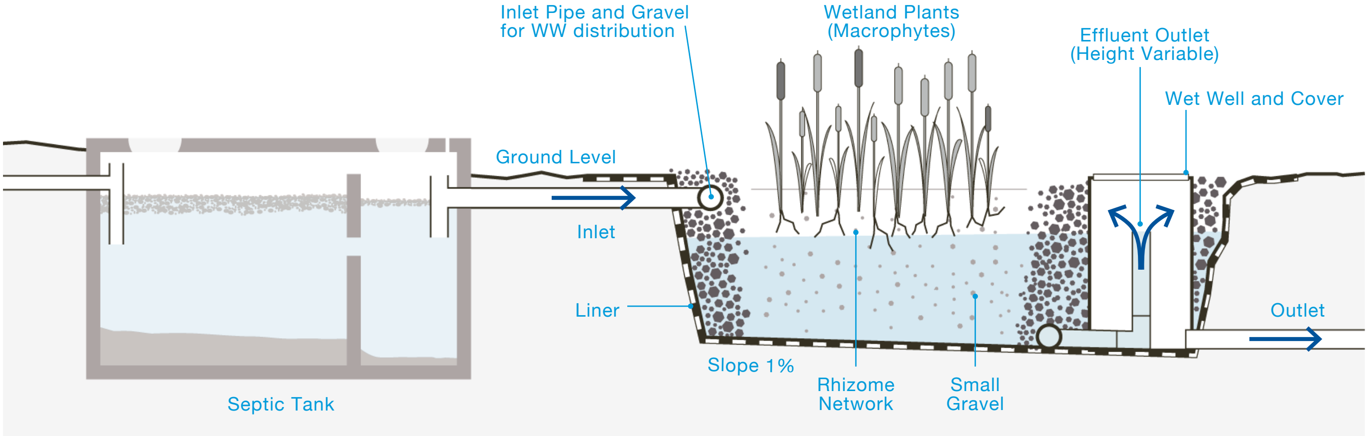

**FIGURE 39**: Cross-sectional view of a horizontal gravel filter with a septic tank as upstream treatment. [39]

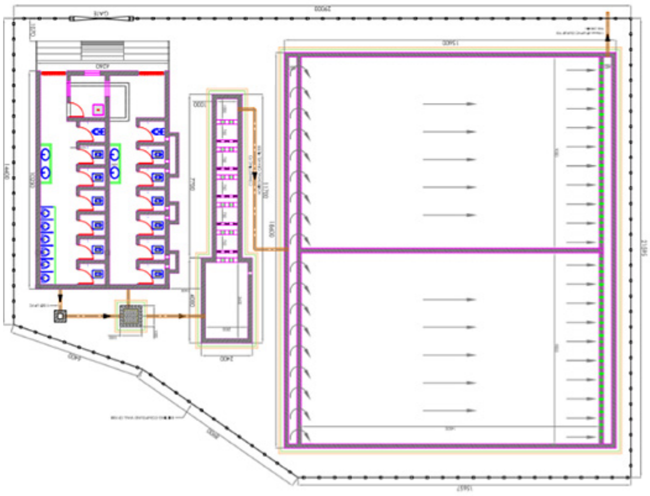

**FIGURE 40**: View of a horizontal filter in Bangalore. From left to right: community toilets blocks, settler and ABR/AF, horizontal filters. [40]

**FIGURE 41**: Horizontal filter in Nepal. [41]

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[39] Source: EAWAG compendium and Epuval NPO for the septic tank.

[40] Source: Detailed Project Report of Sewerage System in Kaverinagar, TTI Consulting Engineers India (P) Ltd.

[41] Source: Key aspects of sustainable sanitation, P. D. Jenssen, M. Pandey, A. Paruch, 2009, Beijing International Environmental Technology Conference.

# Components of an Horizontal Filter

The horizontal filter is a watertight basin made with sand, clay or concrete bottom slab and concrete walls of 20 cm, or PVC/HDPE liner of 1 mm thickness, and are resistant to UV. “Liner–Passes” allow feeding by pipes through the liner.

The bottom and the walls can be built with concrete or plastic plates covered by geotextiles and geomembranes. In sandy or clayish soils, the liners and geotextiles can be laid on the inclined walls.

**FIGURE 42**: Filter material: different types of gravel and helophyte plants.

The filter is filled with pea gravel of diameter between 4 and 10 mm. The gravel must be clean – without any dust or sludge, in order to avoid rapid clogging.

If angular gravels are used, the liner must be covered by a geotextile to avoid piercings.

As soon as the horizontal filter is fed by wastewater, it will be planted with helophyte plants like reeds, typha, or cattail, which are typically gowing in swampy environments.

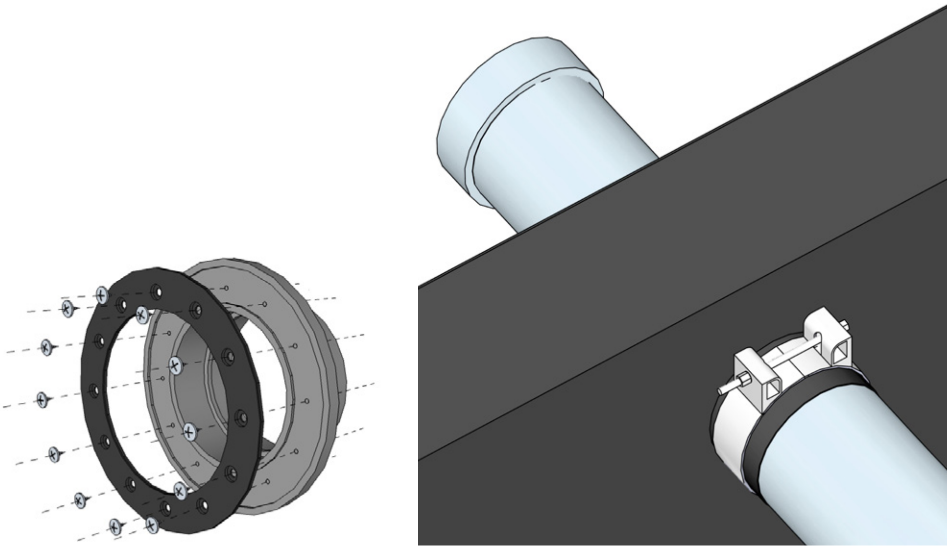


**FIGURE 43**: Liner-pass (left) and clamp (right): components of systems to pass wastewater through liners.

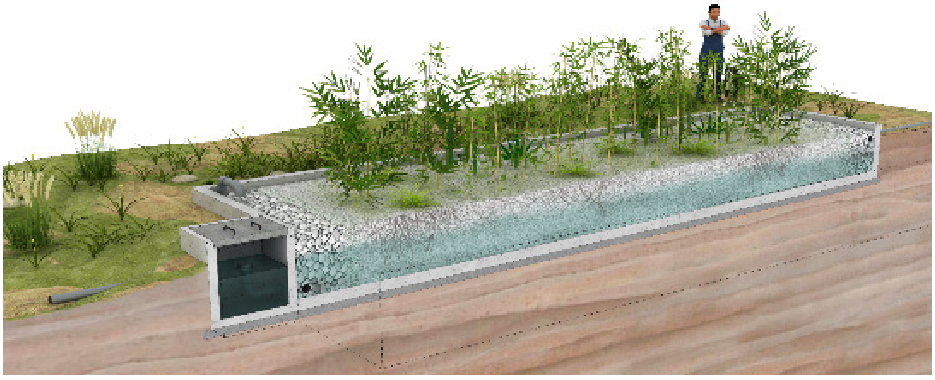


**FIGURE 44**: Horizontal filter with plants. [42]

[42] Source: Epuval NPO.

## Design Considerations

1. Length to Width ratio of a horizontal filter should be at minimum 1.

2. Inlet: It is strongly recommended to distribute the wastewater by a 110 mm PVC pipe plus T-piece, and perforated distribution pipes: 2 cm-holes should be added every 10 cm. These pipes should be placed on the surface of the pea gravel. Distribution could be improved in a 40–80 mm pebble layer, with a length of 30–60 cm, located under the inlet pipes.

3. Gravel with 8–16 mm diameter can separate the pea gravel and the pebbles. (See Figures 45, 46 & 47).

4. Outlet: these are reverse inlet layers. Treated water is collected in horizontal pipes with a diameter of 110 mm laid at 40 cm under the gravel surface, with elbows and vertical pipes for control and cleaning. These pipes are connected to a tee and are perforated by 2 cm holes every 10 cm. The liquid passes in the tee to a chamber with elbow and overflow pipe. A drain pipe evacuates the treated wastewater to the next treatment. (See Figure 48). An horizontal filter is permanently under water because the effluent is discharged by outlet by overflowing through the outlet.

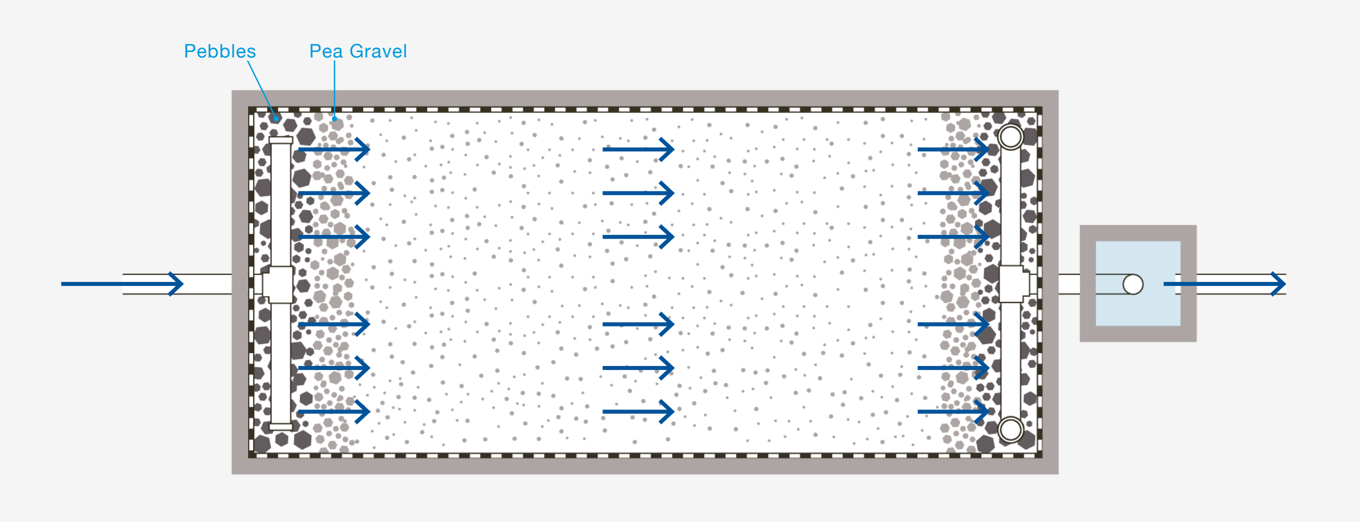


**FIGURE 45**: Plan view of a horizontal filter and the plug flow. [43]

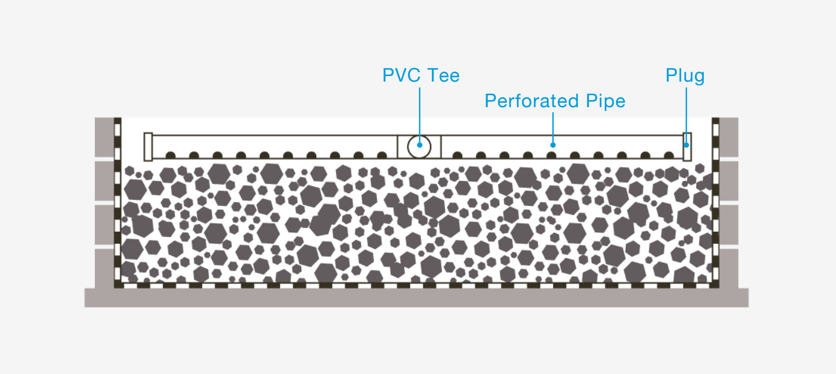


**FIGURE 46**: Inlet pipes and pebbles layer. [44]

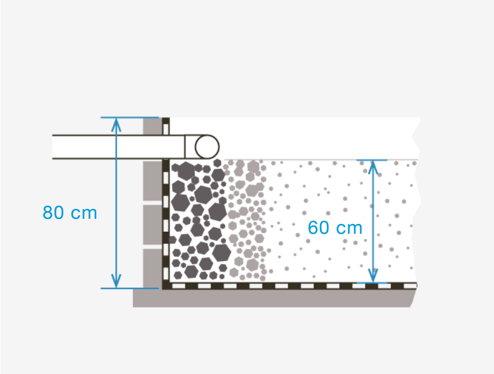


**FIGURE 47**: Height of the wall: 80 cm; Height of gravel layer: 60 cm. [45]

[43] [44] [45] Source: Epuval NPO.

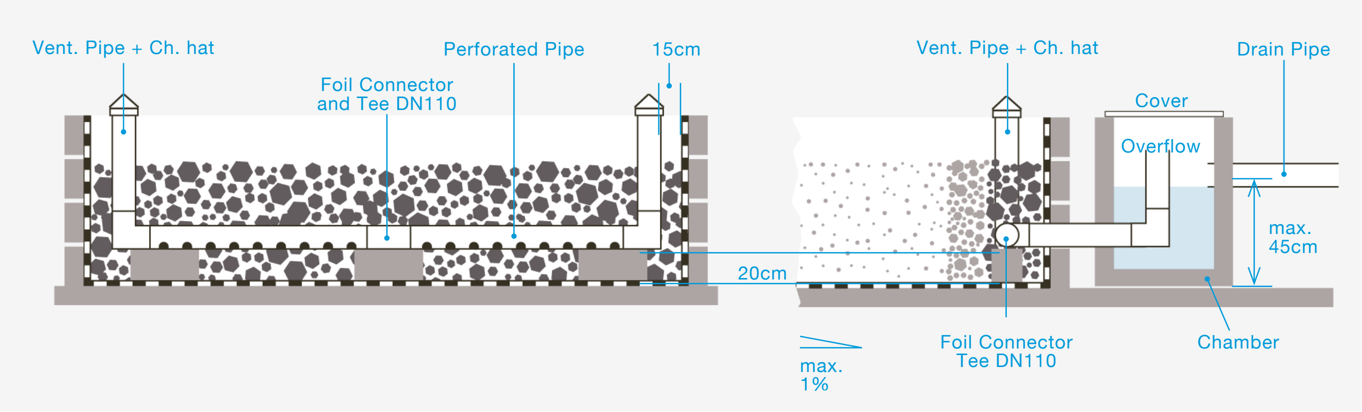


**FIGURE 48:** Views on details of the outlet system of a horizontal filter. [46]

# Treatment Processes of an Horizontal Filter

Horizontal filters work with biological degradation mainly done by anaerobic bacteria in zones without air, and partially by aerobic bacteria.

Air is dissolved in the upper layer and its diffusion happens through plant rootlets.

Bacterial activities are carried out by bacteria which are free or fixed on both gravel surfaces and plant roots.

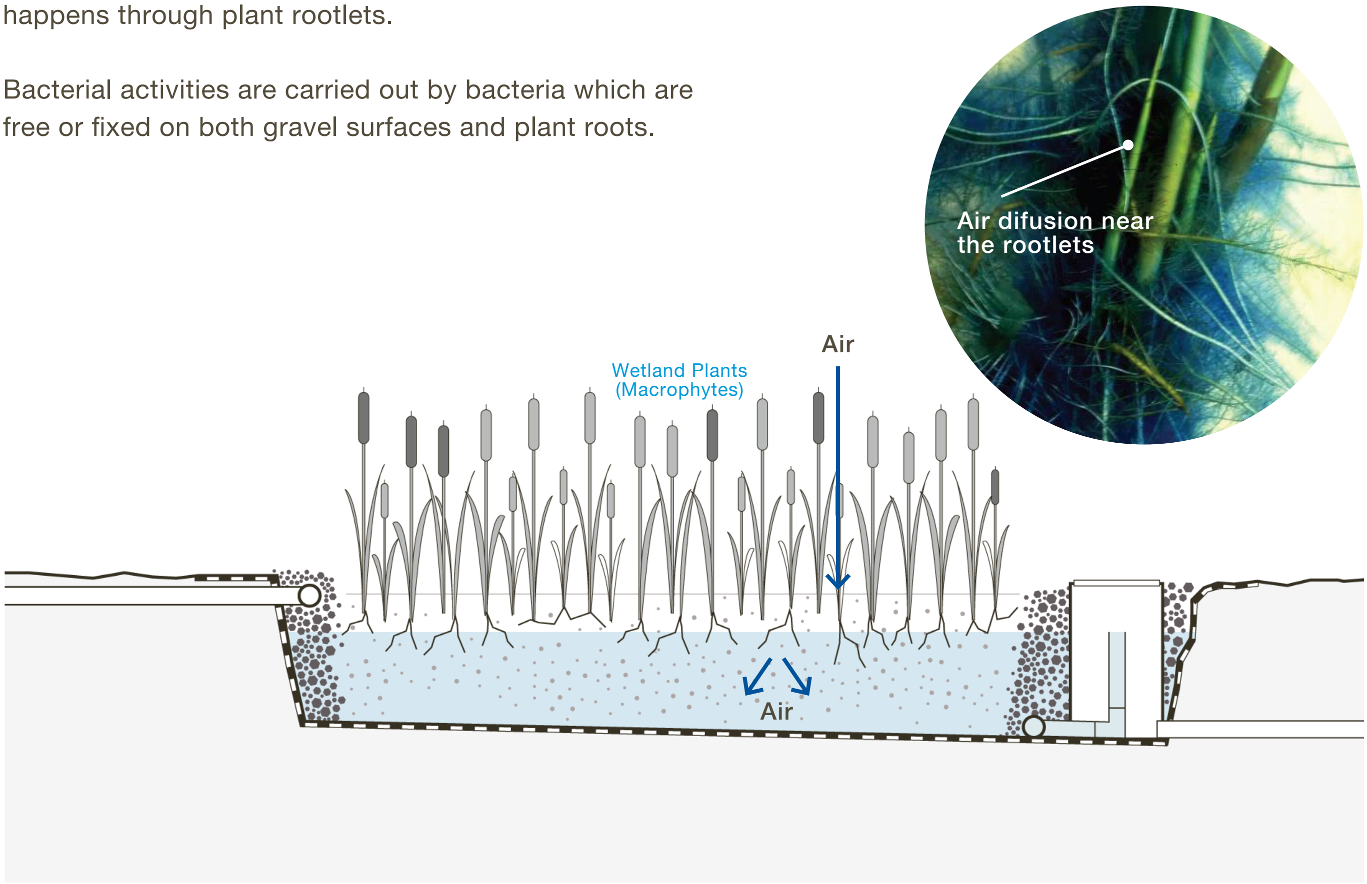


**FIGURE 49**: Aeration processes in horizontal filters.

[46] Source: Epuval NPO.

Plants play important roles in a horizontal filter. They stimulate diversity and quantity of the bacteria; however, they can only "catch" a small amount of the nutrients contained in the wastewater. Plants are not nutrients "pumps" and their de-clogging function is not proven.

Suitable plants for horizontal filters are:

*Phragmites Australis*
**(Common Reed)**

*Typha*
*Latifolia*

*Phalaris*
*Arundinacea*

*Arundo Donax*
**(Ksab)**

*Iris*
*Pseudiacorus*

# Examples of Horizontal Filters

**FIGURE 50**: Horizontal filters built by Epuval in Belgium (top left & right).

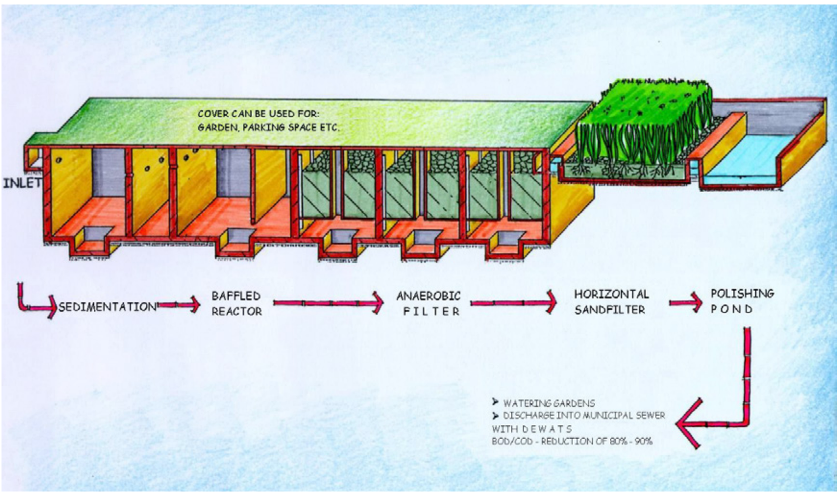
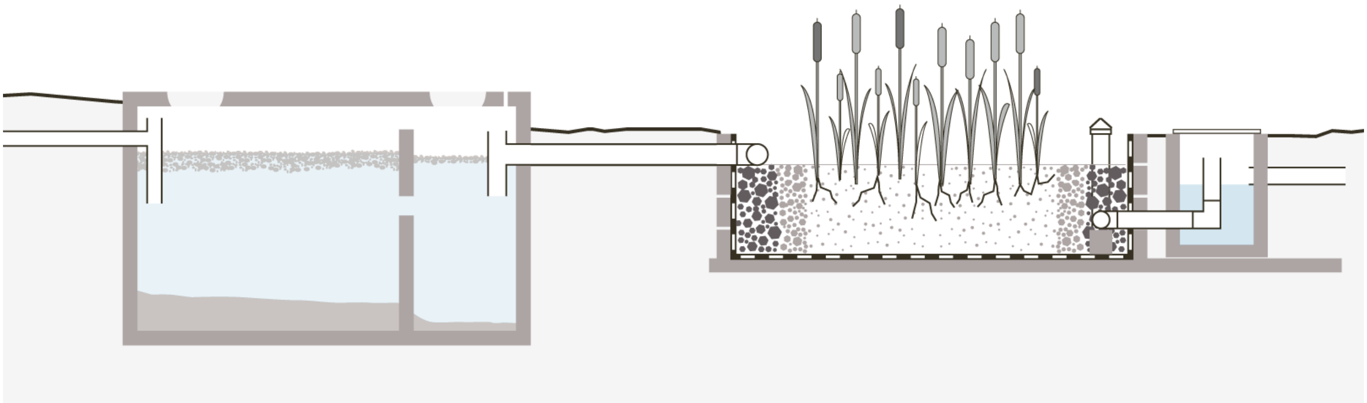


**FIGURE 51**: Horizontal filter integrated in a Decentralized Wastewater Treatment System (left). [47]

**FIGURE 52**: Horizontal Filter in France (left).

**FIGURE 53**: Cross-section view on a horizontal filter design for households in Belgium (bottom). [48]



[47] Source: DEWATS, Heinz-Peter Mang, November 2018, Sanitation Workshop Pyongyang, DPRK.

[48] Source: Epuval NPO .

# Performance of Horizontal Filters

Performance of an horizontal filter is related to its hydraulic charges, organic loads, pre-treatment system, sizing, retention time, environmental parameters, temperature, quality of the constructed components, and quality of operation and maintenance.

The mechanisms for pathogen reduction are competition, predation, filtration and sedimentation. The performances are linked to temperature and retention time.

Reminder: Fresh wastewater contains up to 107 coliforms/100 ml (7 $Log_{10}$ ).

**TABLE 8**: Parameters and Indicators to measure the performances of horizontal filters. [49]

| Parameters | Performances % | Max. Reduction % |
|---|---|---|
| COD | 76 – 84 | 95 |
| BOD5 | 82 – 88 | 98 |
| SS | 84 | |
| $N\text{-}NH_4$ | 48 | 100 |
| Nt | 42 – 48 | 48.2 |
| Pt | 51 – 93.5 | 100 |

| Indicator | Performances |
|---|---|
| Bacteria | 1 – 4 $Log_{10}$ |
| Viruses | 1 – 2 $Log_{10}$ |
| Protozoa | 2 $Log_{10}$ |
| Helminths | 2 $Log_{10}$ |

# Calculation for Sizing

The sizing of a horizontal filter is based on the days calculated as Hydraulic Retention time (HRT). The water capacity of a horizontal filter is the volume of water in the gravel porosity:

HRT x daily feedings = water capacity (porosity)

Recommended HRT is between 2 to 4 days.
Higher HRT increases the pathogen removal.

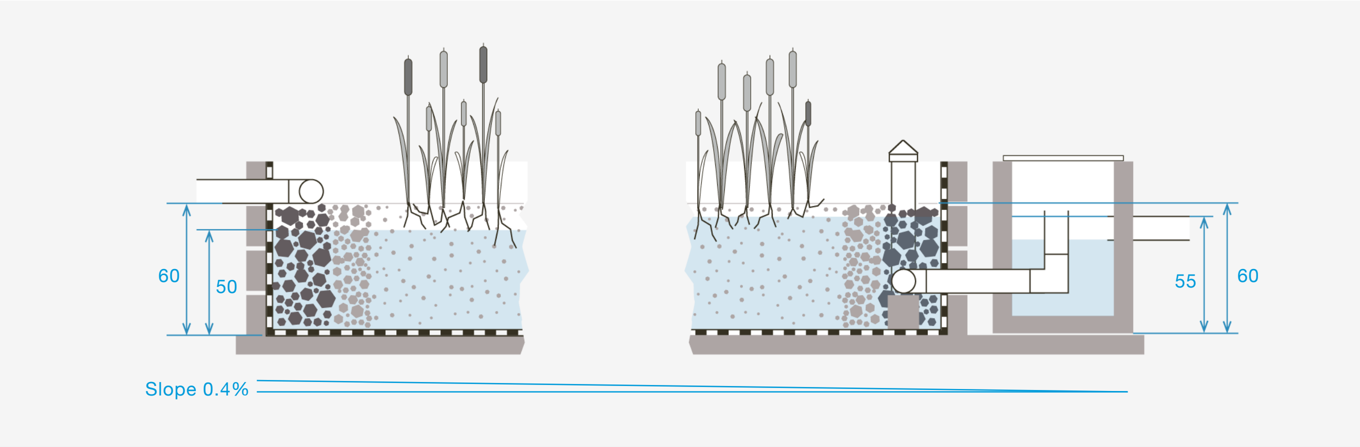


**FIGURE 54**: Slope and levels in a horizontal filter. [50]

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[49] Source: Data from different articles and field experiences in Germany.
[50] Source: Epuval NPO.

## Further recommendations

1. Bottom slope: 0.4% (maximum: 1%) corresponding to the hydraulic gradient.
2. Gravel height 60 cm and water height 50–55 cm.
3. Maximum length 10 m, with tolerances up to 20 m for wastewater with high organic concentrations.
4. Maximum width 10 m in order to respect a good distribution (plug flow). If calculations give more than 10 m, it is necessary to make a division in parallel filters.

## Main factors for calculation

1. Maximum organic load = 10 g BOD5/$m^2$.d
2. Hydraulic Retention Time: minimum 2 days; higher if temperature < 20°C.
3. Gravel depth: 0.5 m; length = 10 m, L/W = minimum 1, mean porosity = 30%; theoretical 43% with round pebbles, but will decrease after some months because of sludge and roots.
4. Performances increase when:
   - Filter area increases.
   - Temperature increases.
   - Organic and / or hydraulic loads are reduced.

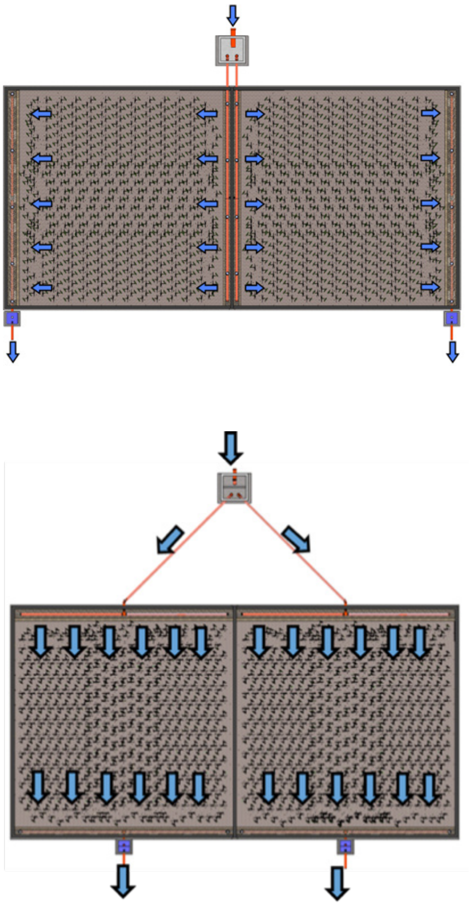


**FIGURE 55**: Division of horizontal filter. [51]

**Calculation Example 1:**

2.5 $m^3$/d wastewater fed in a filter with 0.5m water in gravel of 6–10 mm and porosity of 30%

→ 2.5 $m^3$/d x 3 d (HRT) = 7.5 $m^3$ water capacity
→ 7.5 $m^3$ / 0.3 = 25 $m^3$ filter capacity
→ 25 $m^3$ / 0.5 m (water height) = 50 $m^2$ filter area
→ Filter: 5 m (W) x 10 m (L)

The recommended organic loading is 10g BOD5/$m^2$.d

**Calculation Example 2:**

2.5$m^3$/d wastewater with 250mg BOD5/l*
(250g BOD5/$m^3$)

Total BOD5 load:
250g BOD5/$m^3$ x 2.5 $m^3$/d = 625 g BOD5/d

Area of the filter:
(625g BOD5/d) / (10 g BOD5/$m^2$.d) = 62.5 $m^2$

* “pre-treated” wastewater from Anaerobic Baffled Reactor (ABR), Anaerobic Filter (AF), Biogas-Digester or Septic Tank.

---

[51] Source: Epuval NPO.

**Based on temperature and concentrations:**

$$C_e = C_a e^{-K_T.t} \qquad t = \frac{A.Y.n}{Q}$$

**where**

→ $A$ = Filter area ($m^2$)
→ $Q$ = WW flow ($m^3/d$)
→ $C_a$ = influent concentration (mgBOD5/l)
→ $C_e$ = effluent concentration (mgBOD5/l)
→ $K_T$ = Constant at temperature t
→ $Y$ = water height (m)
→ $n$ = porosity of the media
→ $t$ = Hydraulic retention time

$$A = \frac{Q.(\text{In}\,(C_a)) - \text{In}\,(Ce)}{K_T.Y.n}$$

**where**

→ $A$ = Filter area ($m^2$)
→ $Q$ = WW flow ($m^3/d$)
→ $C_a$ = influent concentration (mgBOD5/l)
→ $C_e$ = effluent concentration (example: 30 mgBOD5/l)
→ $K_T$ = Constant at temperature t
→ $Y$ = water height (0.5 m)
→ $n$ = porosity of the media (30%)
→ $t$ = Hydraulic retention time

$$K_T = K_{20}\,\Theta^{(T-20)}$$

**where**

→ $K_T$ = Constant at temperature t
→ $K_{20}$ = Constant at 20°C = 1.1 for BOD5
→ $\Theta$ = Constant = 1.06 for BOD5
→ $T$ = wastewater temperature

**Example**:
2.5$m^3$/d wastewater with 250mg BOD5/l (Ca), 30mg BOD5/l (European Community standard)

→ $Y$ = gravel depth 0.5 m;

→ Temperature = 28°C

$$K_T = K_{20}\,\Theta^{(T-20)} = 1.753$$

$$A = \frac{Q.(\text{In}\,(C_a)) - \text{In}\,(Ce)}{K_T.Y.n} = 20.16\ m^2$$

→ Calculated area is 20.16 $m^2$

→ HRT is too short:

$$t = \frac{A.Y.n}{Q} = 1.21\ d \quad \text{(minimum 2 – 4 d)}$$

→ if HRT = 2.4 days → $A = 40.32\ m^2$

→ if HRT = 3.6 days → $A = 60.63\ m^2$

## Conclusions from different calculations:

→ 20$m^2$ is the theoretical area to have a good effluent concentration. But the other criteria are not respected.

→ 40 to 60$m^2$ is recommended.

# Operation & Maintenance of an Horizontal Filter

Horizontal filters can be operated without daily control, but a minimum of attention is required, at least once per month.

**Maintenance work focusing on plants in and around the system:**

1. Eliminate trees around the filter (within 3 m); the roots can impair the filter walls.
2. Eliminate unwanted weeds and leaves, plastics and other rubbish from the filter surface (important for the first 2 years) and add plants / reeds if necessary.
3. Harvest plants and reeds for compost, animal fodder or cooking fuel.
4. Replace dead plants.
5. Maintain access way.

**Maintenance work focusing on system components:**

1. Check flow and water level: outlet below gravel surface.
2. Maintain dams if there is risk of flood or mudslide.
3. Verify integrity of pipes, chambers, covers and membrane.
4. Check liner(s), plants, and covers.
5. Clean pipes and chambers.
6. Replace broken pipes, elbows, covers, dead plants.
7. Repair leakages in walls, pipes and liner.
8. Adjust water level if necessary by adjusting the outlet pipe.

**TABLE 9:** Planted Gravel FIlters: overview on possible problems and recommended solutions.

| Breakdown | Possible Problems | Solution |
|---|---|---|
| No water in the filters, dried plants | Upstream problems (clogged pipes, broken connection, no feeding, etc.) | • Verify the flows in the pipes and ask for feedings. |
| | Evapotranspiration > water supply | • Add more water. |
| | Seasonal period (hot climate, winter) | — |
| Roots in the pipes and drains | Too much plants | • Disassemble the pipes and eliminate the roots. |
| Water on the filter surface | Outlet vertical pipe too high. | • Adjust water level by shortening the outlet pipe. |
| | Lack of gravel. | • Add gravels. |
| | Filter clogging | • Analyse the upstream treatment systems.<br>• Clean the pipes.<br>• Pump the water in the filter.<br>• Clean the pebbles (and gravel if necessary).<br>• Add new gravels if required. |

**PLANTED GRAVEL FILTERS**

# Vertical Filter

A vertical filter serves as secondary treatment of wastewater. In some cases, a vertical filter can be fed by raw and low concentrated wastewater coming from a sewer.

Vertical filters should be operated with pre-screening and batch feeding systems. As pre- treatment of the wastewater before it flows into the vertical filter, several systems could be used, such as a septic tank, a biogas-digester, an Anaerobic Baffled Reactor (ABR), or an Anaerobic Filter (AF) for sludge settling, reduction of greases, plastics, papers, partial degradations of sludge and wastewater.

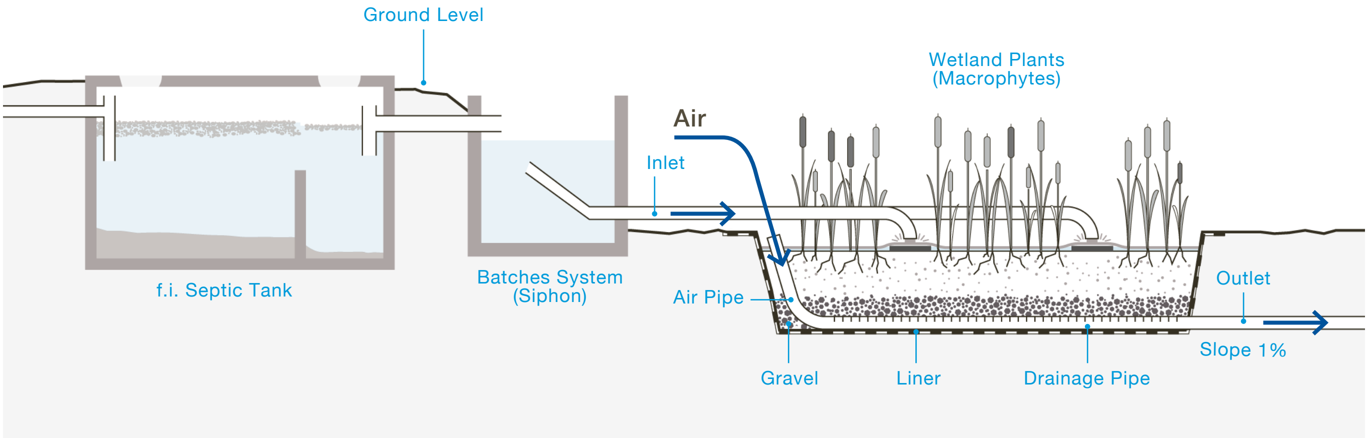


**FIGURE 56**: Cross-section view on a Vertical Filter with Septic Tank as pre-treatment and Siphon System for batch-wise feeding. [52]

## Components of a Vertical Filter

A Vertical Filter provides aerobic treatment of wastewater.

The filter basin is watertight. Bottom and walls are covered by a liner. It is filled by gravels and sand with layer of gravels and sand of, at least, 80 cm. The wastewater is spread on the surface and flows vertically into the filter media. The sand surface is covered by plants. The treated wastewater is collected in a drain laid on the bottom.

The filter media is composed of clean sand and gravel, without any dust or clay. Gravel and sand should be limestone free.

Bottom and walls can be built with concrete or plastic plates covered by geotextiles and liner. In sandy or clayish soils, the liner and geotextile can be laid on the inclined walls. Because of the feeding in batches, the walls must be higher than the filter media to avoid uncontrolled overflows.

[52] Source: EAWAG Compendium for the filter & Epuval NPO.

FIGURE 57: **Liners and liner-passes for Horizontal filters.**

**FIGURE 58**: Tests of liners tightness.

From top to bottom, the filter is composed of 20–40 mm gravel surrounding the drainage pipe, which is of 110 mm diameter, pea gravel and sand. The drainage pipe is connected to aeration pipes.

Except for very small single-family systems, the vertical filter is usually divided into cells, small filters separated by walls or membranes.

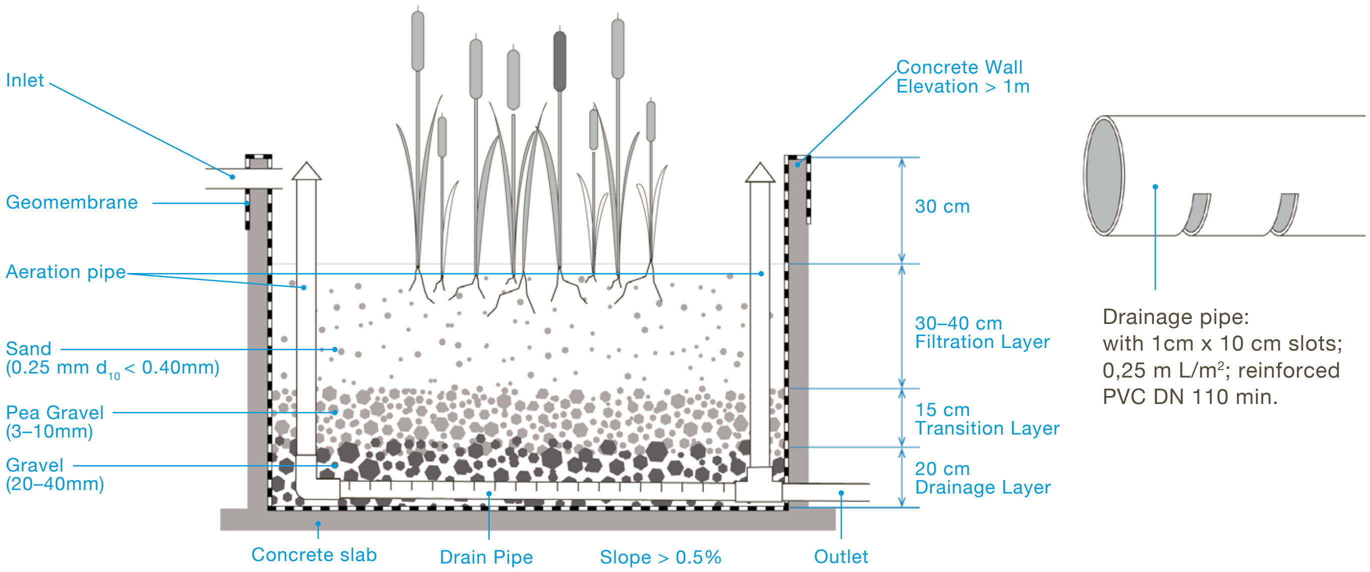


**FIGURE 59**: Sectional view of a vertical filter and details of a drainage pipe. [53]

## 1. Distribution of wastewater to the filter cells:

Alternance of feedings is required because aeration has to take place during the rest period, every day or every 3 days (See Figure 60).

To activate the filter - or all the cells of the filter, it is imperative to distribute the wastewater on the entire filter surface.

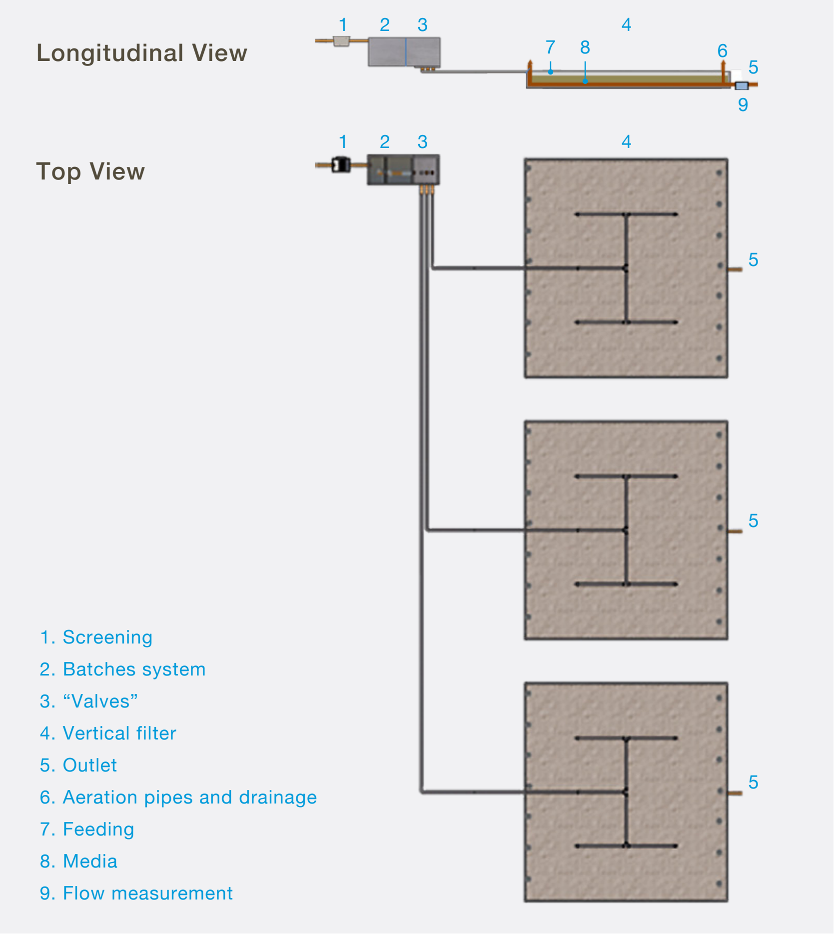


**FIGURE 60**: Longitudinal and top view on vertical filter system with 3 cells for alternating batch feeding. [54]

[53] [54] Source: Epuval NPO.

## 2. Distribution on the filter surfaces

Feeding by batches is best realized by installing a siphon system. It is automatic, but must be controlled, in particular, to allow timely discovery of any wears and tears (See Figures 61 & 62).

The alternative to a siphon and pendula valve, is a reservoir and manual valves plus T-pieces. In this case, manual services, permanent staff and good management are required (See Figures 63 & 64).

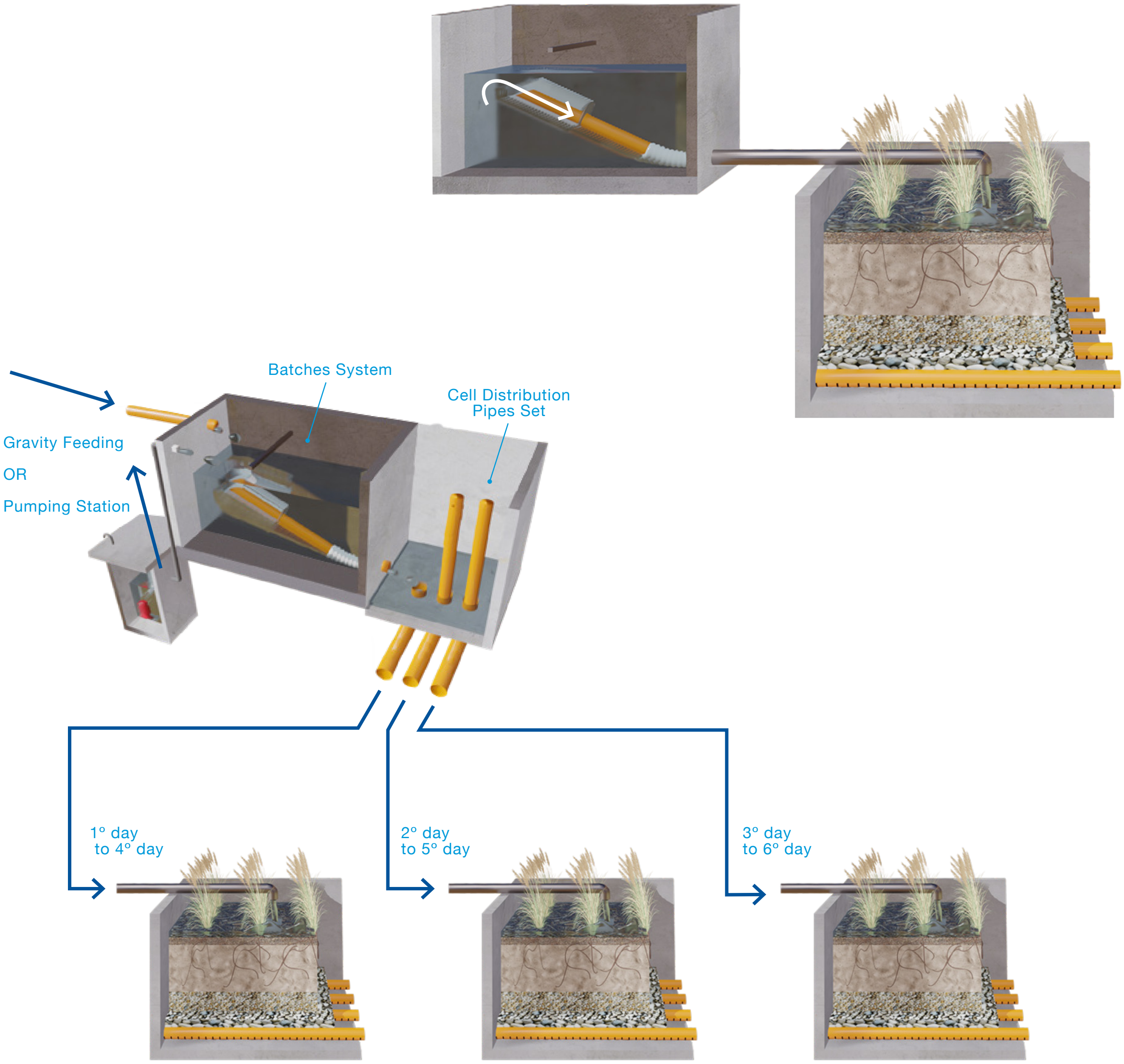
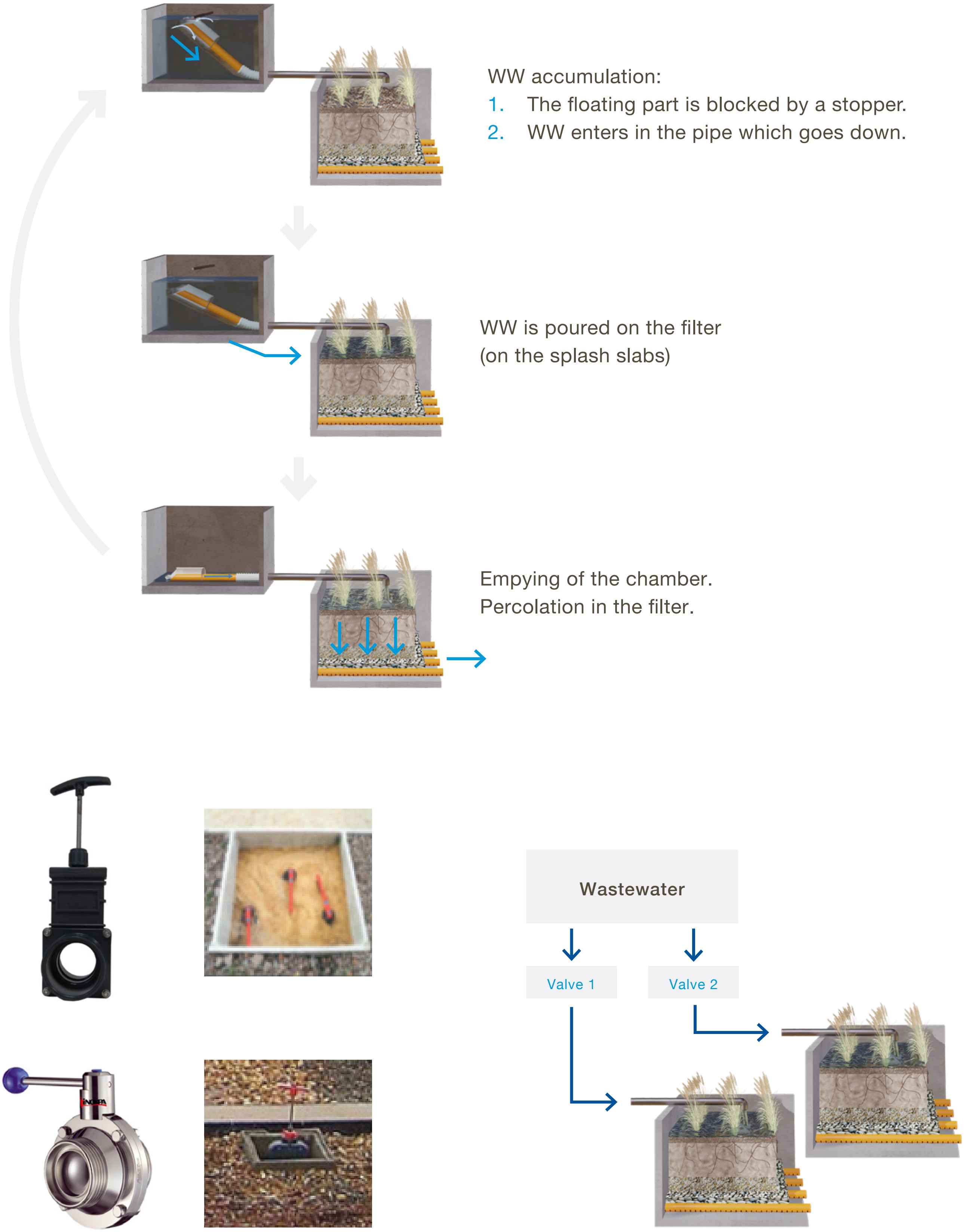


**FIGURE 61**: Feeding cycle with pendula valve / siphon (top). [55]

**FIGURE 62**: Feeding system (bottom). [56]

[55] [56] Source: Epuval NPO.



WW accumulation:

1. The floating part is blocked by a stopper.
2. WW enters in the pipe which goes down.

WW is poured on the filter
(on the splash slabs)

Empying of the chamber.
Percolation in the filter.

**FIGURE 63**: Three wastewater treatment systems with manual valves. [57]

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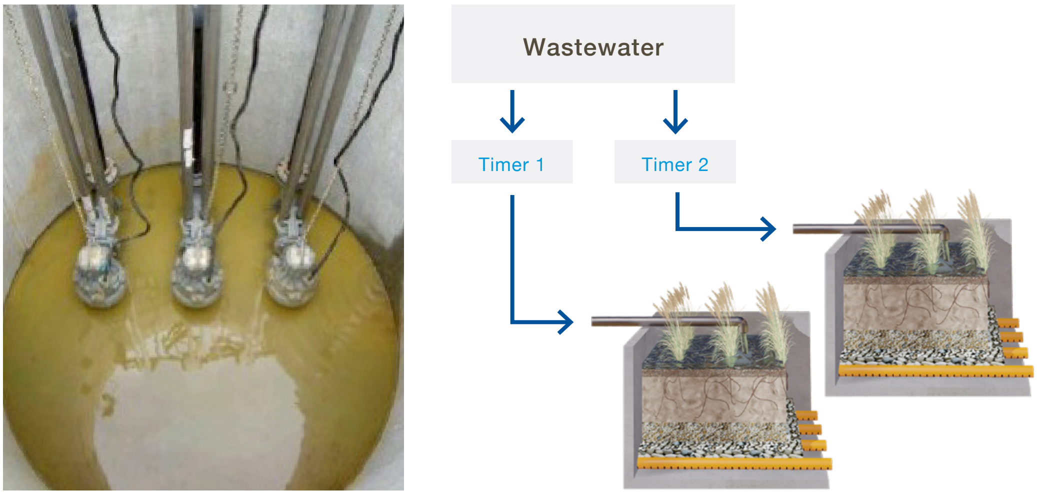
[57] Source: Epuval NPO.

**FIGURE 64**: Alternative to the siphon: reservoir and pumps with timers.



## 3. Feeding pipes in filter cells

The pipes must be dismountable for cleaning. It should be made either of stainless steel, HDPE or PP. PVC is accepted for overflowing systems.

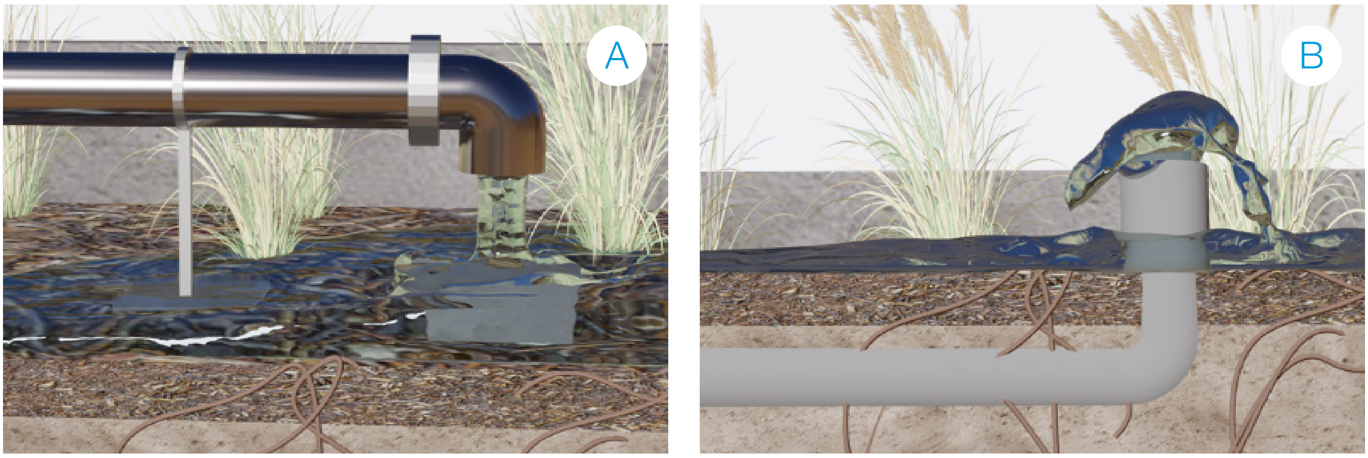


**FIGURE 65**: Feeding pipes in filter cells: (A) Flows on slabs or big pebbles – 1 slab per $5m^2$, (B) Overflowing on pebbles around the pipes – 1 pipe per $5m^2$. [58]

**FIGURE 66**: Feeding by aerial "H" system or overflowing pipes every 2 m. [59]

[58] Source: Epuval NPO.
[59] Source:.STA 43 (left); SATESE 37 (right).

# Examples of Vertical Filters

In Tidili, Morocco, the wastewater treatment chain is as follow: wastewater from 50 households is collected in a sewer; it flows to a screening basin. A siphon system by valves feeds, alternately and in batches, the vertical filters cells before the treated wastewater flows to and through a horizontal filter. It is then used for irrigation.

**FIGURE 67**: Tidili, Morocco: Wastewater treatment chain including vertical filter cells: (1) Screening, (2) “Siphon”, (3) Distribution system / “Valves”, (4) Vertical filter cells. [60]

**FIGURE 68**: Tidili, Morocco: Horizontal filter cells as integrated part of the wastewater treatment chain. [61]

[60] [61] Photos: Marc Wauthelet.

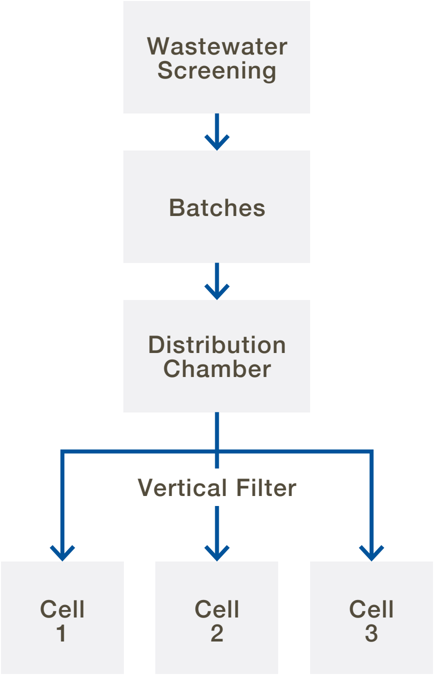
# Treatment Processes

Several processes take place in a vertical filter:

1. Physical filtration (“primary treatment”)
   - → The wastewater is flowing in batches on the filter surface.
   - → The upper sand layer filters and retains the suspended solids.
2. Biological degradation by aerobic microorganisms in the filter media
   - → Biological activities of aerobic bacteria in the upper layer reduce the COD and BOD by 30% and contributes to the sludge mineralization.
   - → The aerobic process results in high nitrification; denitrification needs a post-treatment system such as horizontal filter.
   - → Phosphorus is partially fixed in sludge.
   - → If retention times are short, pathogens reduction is low.

In a Vertical Filter secondary treatment of wastewater is done through aerobic processes. They need to alternate between aeration and feeding periods. Aerobic microorganisms, such as protozoa, bacteria, microscopic fungi and microalgae, are fixed on and in the filter media, either in biofilms or free. Aerobic conditions mean alternations in space and time. The filter is divided in cells alternately fed. The technique aims to develop and “maintain” conditions for micro- organism growth, i.e. aeration and drainage. The micro-organisms mineralize the organic matter through oxidation.

Main aeration is achieved through rest periods which must be at minimum equal to the feeding periods; some suggest a double time for the rest period. To achieve this, 2 or 3 cells must be built in parallel (See Figure 69).



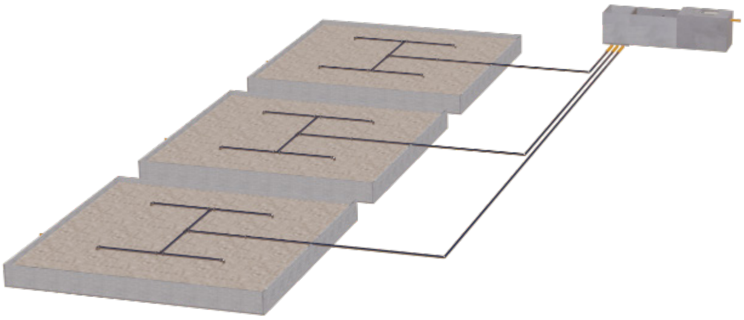


**FIGURE 69**: Vertical filter divided in three “cells” alternately fed with wastewater. [62]

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[62] Source: Epuval NPO.

In a vertical filter, the balance between feeding and aeration must be respected. Microorganisms are more active in the accumulated sludge when fixed on the filter media (See Figures 70 to 73).

**FIGURE 70**: Vertical filter partially covered by sludge (top). [63]

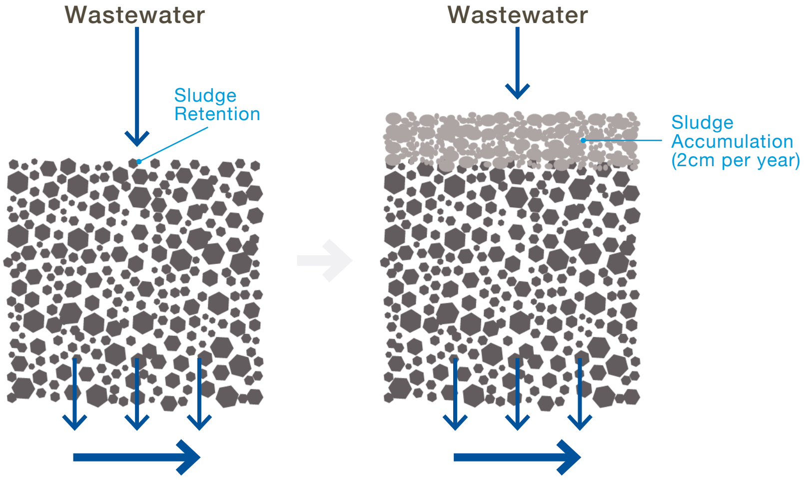
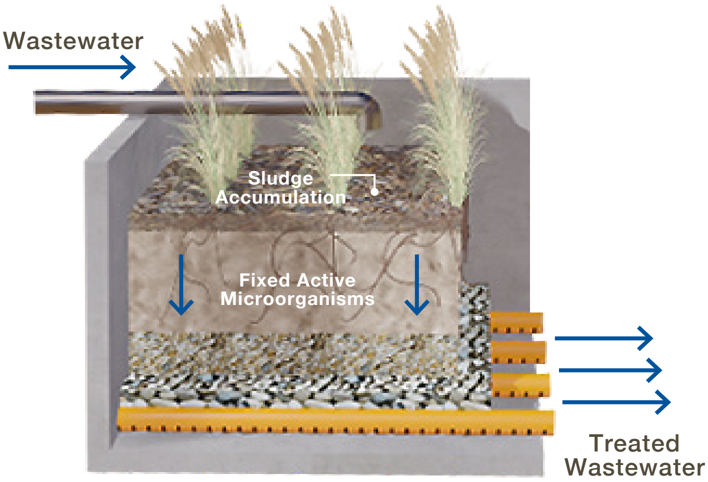
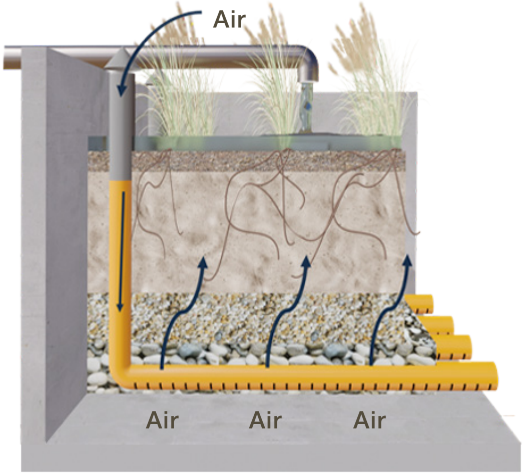


**FIGURE 71**: Accumulation of sludge on vertical filter (right). [64]

**FIGURE 72**: Biological activities in the vertical filter (bottom left). [65]

**FIGURE 73**: Ventilation through the drainage pipes (bottom right). [66]





[63] Photo: Marc Wauthelet, Morocco.
[64] [65] [66] Source: Epuval NPO.

Aeration can be improved when the vent pipes are connected to the drainage system.

Plants, esp. reeds, participate in the sludge mineralization. They reduce the surface temperature by providing shadow, hence improving the environment for micro-organisms development. They also accelerate the infiltration through the movements of their stems under the action of the wind.

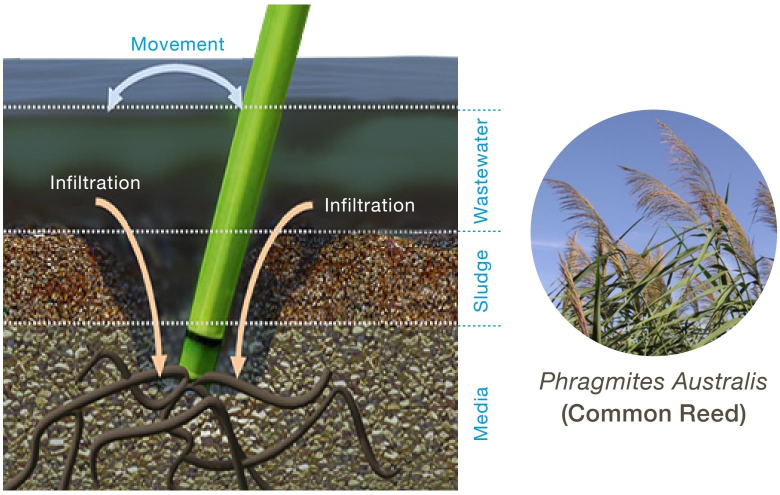


**FIGURE 74:** Reeds are the most suitable plants for vertical filters. [67]

## Performances

Performances of Vertical Filters are correlated to the hydraulic charges, organic loadings, pre-treatment systems, sizing, retention time, environmental parameters, such as temperature, quality of the components including filter media, as well as Operation & Maintenance. Performance will improve over time.

**TABLE 10:** Parameters to measure performances of Vertical Filters.

| Parameter | Performances |
|---|---|
| BOD5 | > 85 % |
| SS | > 80 % |
| COD | > 75 % |
| Nitrogen | > 50 % |

## Calculation for Sizing

Batches must be measured to avoid:
(i) bad distribution of wastewater, when the hydraulic load is lower than 2.5 cm by batch; and (ii) odor, creation of preferential infiltration ways, too short HRT and decreasing performances, when the hydraulic load is higher than 5 cm by batch.

Main parameters of sizing are:

- → max. 150 g BOD5/m².d
- → max. 300 g COD/m².d
- → 25–30 g N/m².d
- → 2.5–5 cm / batch (and max. 0.37 m/d)

**Calculation Example 1:**
3 vertical filter cells working alternately with 3.5 activity days and 7 rest days:

- → Total area of the filter = 3 x active cell area
- → Sizing for 1 Person (P.E. = 60 g BOD5/d)
- → 1.2 m²/ P.E.

$$\text{Area / P.E.} = \frac{(60\ \text{gBOD5/PE})}{(150\ \text{gBOD/m}^2)} = 0.4\ \text{m}^\wedge 2\ /\ \text{P.E.}$$

With 3 alternated cells:
3 x 0.4 m² / P.E. = 1.2 m² / P.E.

---

[67] Source: Epuval NPO.

**Calculation Example 2:**

10 m³ wastewater/d

BOD5 = 300 mg/l . 3000 g BOD5/d

Calculated area per cell: $\frac{(3{,}000 \text{ g BOD5/d})}{(150 \text{ g BOD/m}^2)} = 20 \text{ m}^2$

→ Hydraulic Load is too high: 10 m³/d / 20 m² = 0.5 m/d

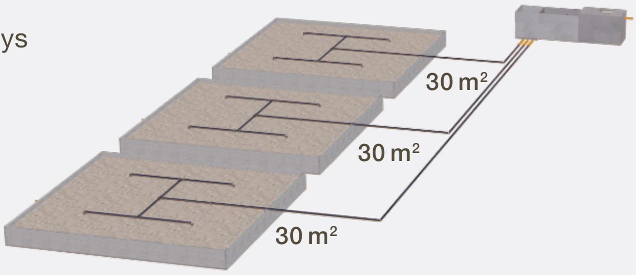
→ Area must be higher: 30 m²; then: 0.33 m/d

→ Filter = 3 x 30 m² = 90 m²

3 filter cells working alternately with 3.5 activity days and 7 rest days:

0.33 m/d on the active cell → 10 batches (3.3 cm)

1 batch = 0.033 m x 30 m² = 0.1 m³



Batch volumes can be calculated between a minimum and a maximum, as shown in Table 11.

TABLE 11: **Calculation of minimum and maximum batch volumes.**

| Cell area (m²) | Min. batch (liters) | Max. batch (liters) |
|---|---|---|
| 8 | 200 | 400 |
| 10 | 250 | 500 |
| 15 | 375 | 750 |
| 20 | 500 | 1,000 |
| 30 | 750 | 1,500 |
| 50 | 1,250 | 2,500 |
| 100 | 2,500 | 5,000 |
| 150 | 3,750 | 7,500 |
| 200 | 5,000 | 10,000 |

# Operation & Maintenance of a Vertical Filter

## An appropriate O&M based on observations and depending on the wastewater quality, filter media, and temperature must be programmed.

Without proper O&M practices, after some months too much sludge accumulates, the flows are reduced (clogging) and gases transfers are progressively stopped.

**TABLE 12:** List of operational tasks.

| Operational task | Frequency | Working time (minutes) |
|---|---|---|
| Siphon and valves checks | 2 x week | 5 |
| Screening cleaning | 1 x week | 10 |
| Check and filters cleanings (weeds, wastes, ...) | 1 x week | 40 |
| Complete the Operation book | 1 x week | 15 |
| Cleaning of the roads, green park, fences | 1 x month | 120 |
| Cleaning of the chambers and batch system | 1 x month | 60 |
| Emptying and checking of the feeding pipes | 2 x year | 60 |
| Checking the sludge levels and foils | 1 x year | 30 |
| Reed harvesting | 1 x year | 300 |
| Sludge elimination | 1 x 10 years | 960 |

**TABLE 13:** List of maintenance tasks.

| Maintenance task | Frequency |
|---|---|
| Replacement of the siphon (flexible pipes) | 1 x year |
| Pumps replacement | 1 x 2 years |
| Foils repairs | if needed |
| Adding or replacement of sand | depends of suspended solids |
| Pipes repairs | if needed |
| Walls, covers repairs | if needed |
| Fences repairs or replacement | if needed |

## FRENCH DRAIN

# Introduction

Anaerobic systems make it possible to significantly reduce the levels of organic matter and settleable matter in wastewater. In order to purify effluents of anaerobic systems, it is recommended to apply aerobic systems. These can further reduce pollutants as well as pathogens and virus.

Several techniques suitable for refugee camps are presented in this Manual. The present chapter is dedicated to French Drains: they are recommended for post-treatment and infiltration in appropriate soils and are topographically very flexible.

The French drain first came into the public eye in the year 1859 when Mr. Henry French published his book on farm drainage, in Concord, Massachusetts, USA, based on own careful observation. He observed that water runs downhill, and just loves to accumulate in the most inconvenient locations. Suffering from constant flooding, Henry French kept paying attention to water behavior until he figured out the best way to make sure water would run in the direction he wanted, without trying to go against natural laws. Thus, he figured out the concept of what we now call a “French” drain.

However, a typical French drain from 1859 is dedicated to draining the soil; the groundwater is filtered and guided by clay-sealed, geotextile and gravel and collected / transported in perforated pipes (drains).

This technology is applied for flooded soil and to reduce the level of the groundwater. In the wastewater treatment context, the same French drain function is reverse, and the drain must infiltrate the treated wastewater into the soil. Therefore, a wastewater French Drain is always covered to avoid excess rain infiltration from above.

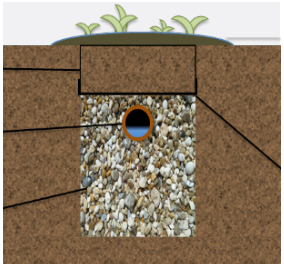
## FRENCH DRAIN

# Concept

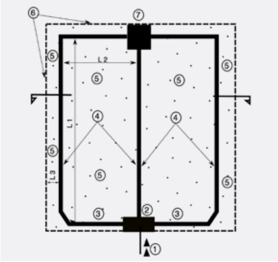
A French drain is one of various infiltration systems, which follow natural laws.

A French drain is a system for draining already treated wastewater into natural soil. It reduces health risks for humans and animals because there is no direct contact with wastewater, and therefore no contact with pathogens. The unsaturated soil filtrates and thus improves the wastewater quality thanks to additional micro-organism activities. However, for shallow groundwater the risks of pollution are high.

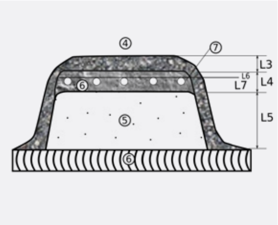
The task of the French drain is to spread the treated wastewater on a large area at low depth. While French drains reduce the risk of groundwater contamination by avoiding direct vertical infiltration, soak pits function with direct vertical infiltration, thus present high risks for groundwater pollution.



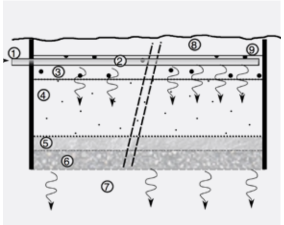
Infiltration Trenches
= French Drains



Infiltration Bed



Infiltration Mound



Sand Filter

Soak Pit: high risk of contamination of groundwater

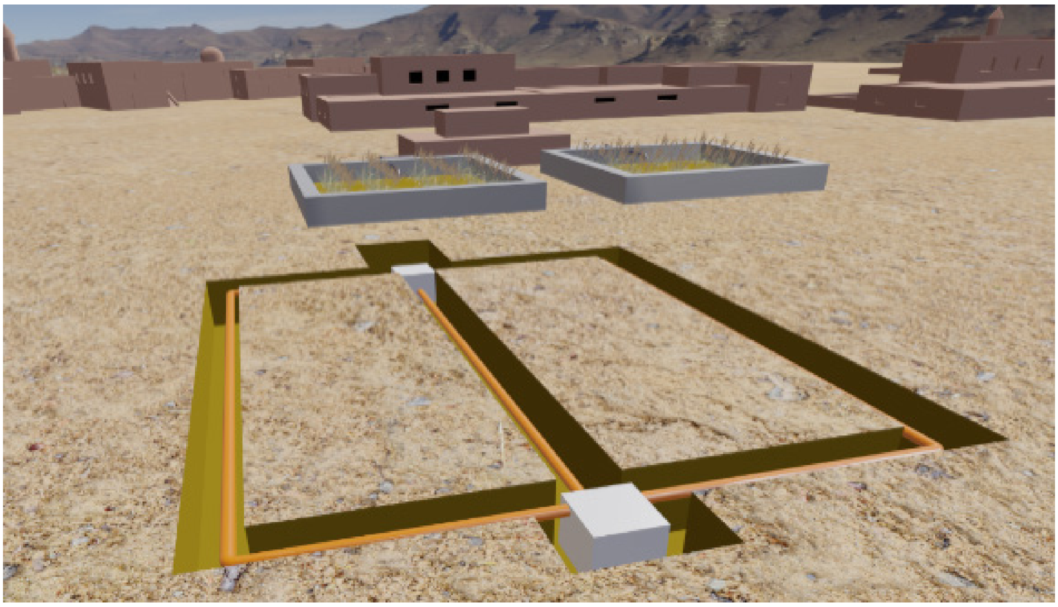


**FIGURE 75: French drain.** [68]

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[68] Source: Epuval NPO.

**FRENCH DRAIN**

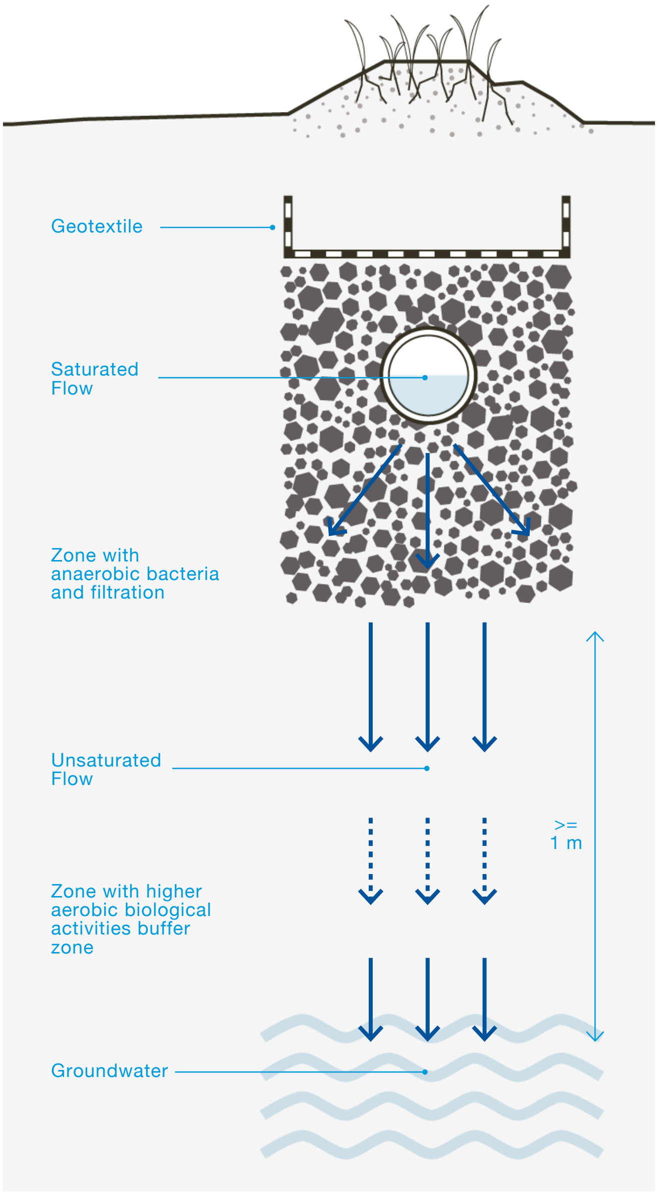
# Technology and Requirements

In French drains, the infiltration must be slow and on a large area. The technology is neither suitable for sandy and gravelly soils, nor for non-porous soils such as clay or rocks.

French drains require large areas for infiltration, which would no longer serve for agriculture or buildings. The technology is applied when there is no possibility for wastewater valorization.The daily flow must be infiltrated within some hours. Therefore, the soils receiving the drainage have to be porous like silt, fine sands or light clays. They must have the capacity to filtrate and to be “biologically active” by hosting micro-organisms. The spreading drain areas have to be adapted to the specific soil capacity.

French drains are trenches in the soil filled with gravel and drains (perforated pipes). The flow is unsaturated in the first decimeters of soil. The microbial activities are high in this buffer zone. Underneath, the flow is saturated, and wastewater goes to groundwater. The drain trenches respecting slopes and perforation diameters must spread the wastewater on the entire dedicated area (See Figure 76).

The trenches of 0.5 m width are excavated in parallel with a minimal distance of 1 m. A chamber distributes equally the inflow in the drains. A connection chamber, at the end of the drains, allows to control the infiltration rate and to clean the system (See Figure 77).



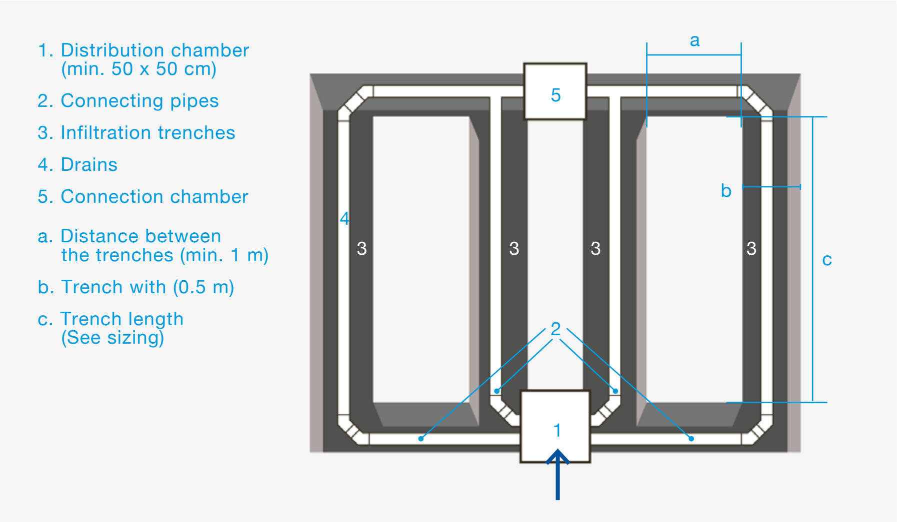


**FIGURE 76**: Sectional view of French drain laid in gravel and soil, displaying the different zones of infiltration, anaerobic and aerobic processes (above).[69]

**FIGURE 77**: French drain system components (left).[70]

[69] [70] Source: Epuval NPO.

It is recommended to place a filter of 200–500 l design volume upstream of the distribution chamber in order to prevent debris or sludge to enter the French drain system. This filter serves also as indicator control chamber for the quality of the incoming wastewater (See Figure 78).

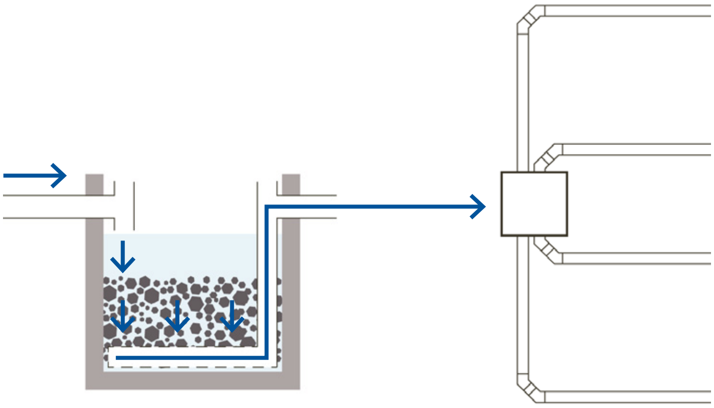


**FIGURE 78:** Filter for debris and sludge installed before French drain system. [71]

The drains are inserted in a gravel layer with a minimal depth of 0.5 m. Some centimeters of rock cover the drain. To avoid soil particles in the drainpipes, and leachates from the drainpipes infiltrating directly into the soil, a geotextile should cover the gravel layer. Note that geotextile should never be placed beneath the gravel layer. The drain is generally a PVC pipe perforated with 3 cm holes every 20 cm (See Figure 79).

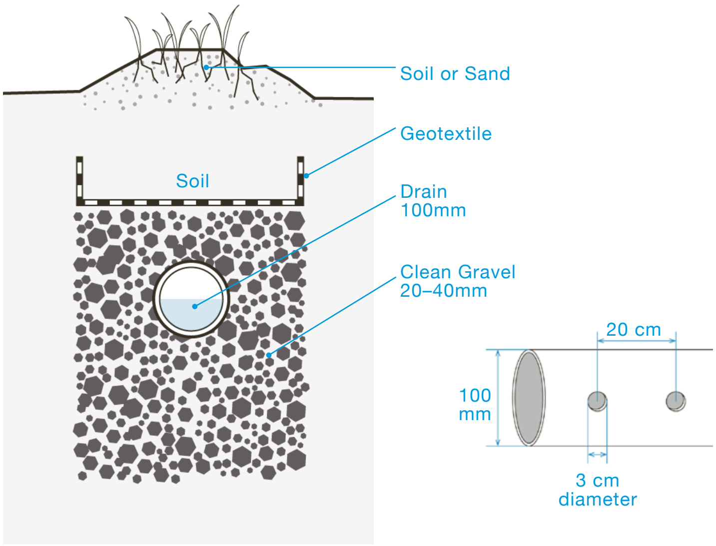


**FIGURE 79:** Technology details of a French drain. [72]

The drain must follow a minimal slope of 0.5 to 1%. The slope will be at its highest degree in case of very filtering soil (See Figure 80).

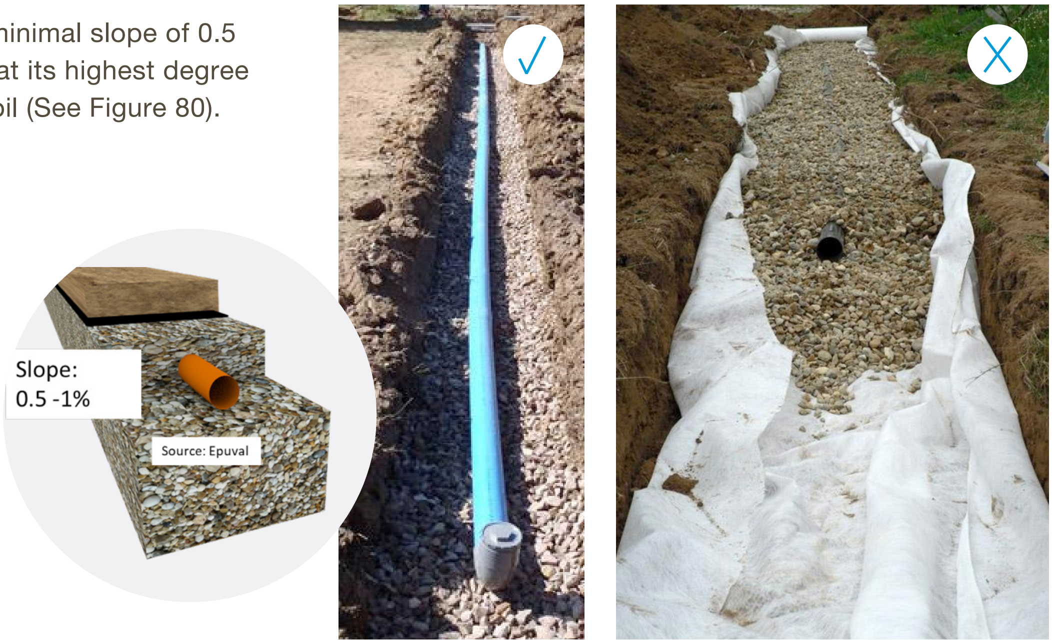


**FIGURE 80:** Illustration of French drain slope; geotextile is not recommended for wastewater (risks of cloggings). [73]

[71] [72] [73] Source: Epuval NPO.

The distribution chamber is connected to 2 or 4 pipes which must be placed at the same level. This chamber can be used as first filter or settler, for example with a baffle system. It provides also access to the pipes for cleaning.

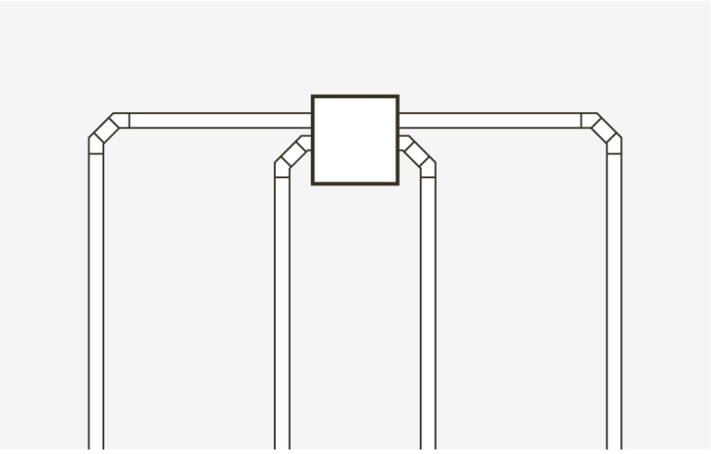


**FIGURE 81:** Layout of pipes leaving the distribution chamber.

**FRENCH DRAIN**

# Soil Properties

Soil properties will change overtime because of wastewater infiltration. Test of infiltration rate of a specific soil must be carried out once water saturation is reached, as a water saturated soil has a lower infiltration rate than a dry soil.

The infiltration rate depends on soil components and its micro- and macro-porosity, such as soil structures and roots. Calcareous soils are partly "dissolved" by wastewater and can be clogged by limestone conglomerates or damaged with time.

The soil permeability defines the infiltration rate. The soil infiltration rate is expressed in l or $m^3$ per $m^2$ per day.

During wastewater infiltration, soils are modified by progressive clogging by soil particles and suspended solids in the wastewater. Sandy soils can be used for longer periods. When the clogging appears around the drains, it is possible to clean the gravel and the pipes. Some centimeters of soil can be removed and replaced. Soil clogging is often irreversible. However, dry periods and water cleaning can improve the permeability.

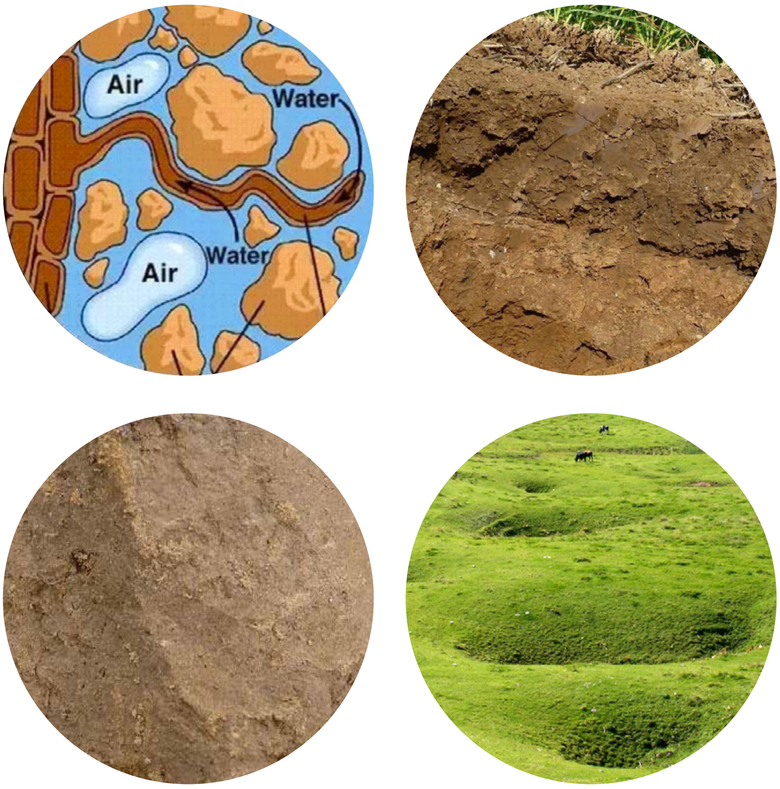


**FIGURE 82:** Soil with dissolution of calcium.

# Calculation for Sizing

The infiltration area ($m^2$) is calculated as:

Daily Flow / Soil Permeability Rate

A high safety coefficient must be applied because of (i) progressive clogging by soil and wastewater particles, depending of the soil characteristics, (ii) rainfalls, which add water to the daily flow of wastewater, and (iii) the duration of infiltration:

$$\text{Infiltration Area } (m^2) = \frac{\text{WW Daily Flow } (m^3/d)}{\text{Soil Infiltration Rate } (m^3/\ m^2.d)} \text{ x Safety Coefficient}$$

In practice, the infiltration rate of the specific local soil is dynamic, because soil composition and structure will be modified during the course of operation of the French drain.

Reference tables are used for the calculation of the area needed for the installation of a French drain system. It has to be noted again, that a French drain receives wastewater only after having passed a secondary treatment.

Trenches should be 50 cm wide, minimum 50 cm below the drain, with a maximum length of 30 m. They are installed in 1 to 4 units, or even more if necessary. The total area stands for the total length of the trenches, the width of the trenches and the distance between the trenches. The minimum distance between the trenches should be 1 m.

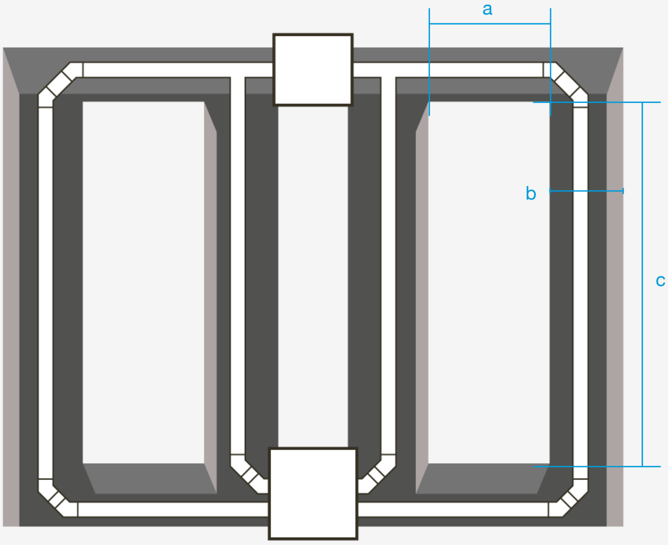


**FIGURE 83:** Layout principles of a French drain system: (a) distance between trenches; (b) width of trenches; (c) length of percolation pipes.

The following reference table presents the calculated area of the French drain systems considering parameters such as soil textures, infiltration rates, and effluent infiltration rates for 1000 l/d.

**TABLE 14:** Parameters for calculation of required area for specific French drain systems.

| Soil Texture | Infiltration Rate (m/s) | Infiltration Rate (mm/h = l/m².h) | Effluent Infiltration Rate (l/m²/day) | Area (m²) for 1,000 litres/day |
|---|---|---|---|---|
| Gravel, Coarse Sand | $> 4.10^{-4}$ | > 1,440 | N.A. | |
| Sand | $4.10^{-4} – 1.10^{-4}$ | 1,440–360 | 50 | 20 |
| Fine Sand | $1.10^{-4} – 8.10^{-5}$ | 360–288 | 42 | 24 |
| Silty Sand | $7.10^{-5} – 3.10^{-5}$ | 252–108 | 32 | 31 |
| Sandy Silt | $3.10^{-5} – 1.10^{-5}$ | 108–36 | 25 | 40 |
| Clayey Slit | $1.10^{-5} – 7.10^{-6}$ | 36–25 | 19 | 53 |
| Sandy Clay | $9.10^{-6} – 7.10^{-6}$ | 32–25 | 12.5 | 80 |
| Silty Clay | $7.10^{-6} – 4.10^{-6}$ | 25–14 | 8.5 | 118 |
| Clay | $< 4.10^{-6}$ | < 14 | N.A. | |

The infiltration rate can be measured with different methods: (i) the test of Porchet, or (ii) the test of Muntz, which is also called “the test of double ring”. It is important to make the tests exactly where the infiltration trenches will be dug and at the correct depth, which is the future level of the trench bottom. At least 3 measurements must be carried out. In addition, environmental observations and soil samplings should be conducted.

Measurement must be also undertaken after the soil is saturated with water. When the measures of infiltration rates are constant, calculations can be made, applying a simple method (example): dig a hole of 15 cm diameter at 0.8 m depth; scratch the walls and the bottom; remove excess soil; place 5 cm of fine gravel on the bottom; fill the hole with clear water for saturation and observe the change of the filling level for at least 4h up to 24h. Fill the hole again with water; measure the infiltration rate until it gives a constant value.

$$\text{Infiltration Rate} = \frac{\text{Level Differences (mm)}}{\text{Time (min.)}}$$

**FIGURE 84**: Measurements of infiltration rate according to the methods of Porchet (above) and Muntz (below).

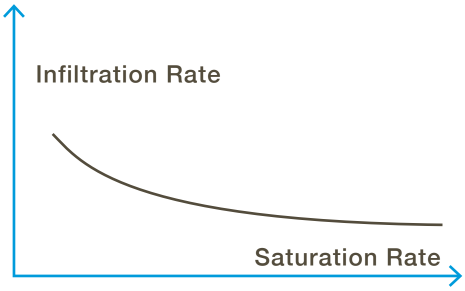


**FIGURE 85:** The period of saturation depends of the soil.

**FRENCH DRAIN**

# Operation & Maintenance

## Workload for Operation & Maintenance (O&M) of the infiltration trenches is light, but important. Health & safety protection for O&M workers is crucial.

O&M work consists of checking the components such as pipes and chambers; cleaning the chambers – especially the distribution chamber; and checking the flow in the pipes and drains.

Furthermore, the cleaning of the soil from plastics, plants and trees is also very important, as no trees are tolerated near the infiltration zone.

The upstream treatment needs to be checked and cleaned out regularly in order to avoid clogging. When the pipes are clogged, a drain snake can be used. Gravel, soil and – if necessary, the drains, can also be replaced.

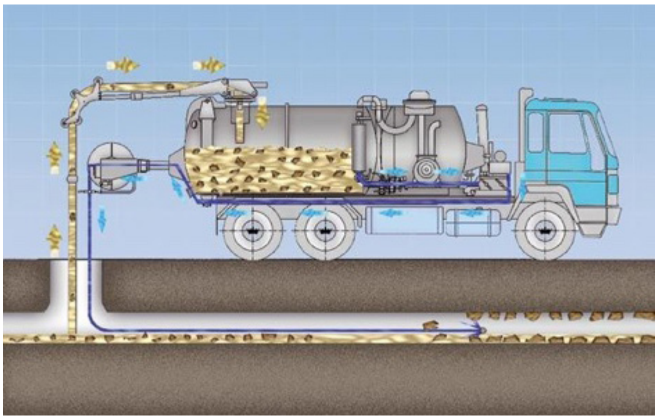


**FIGURE 86:**
**Clogging of a drain by rootlets (top).** [74]

**FIGURE 87:**
**High pressure water jetting / Drain snake (center).**

**FIGURE 88:**
**Desludging truck (bottom).**

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[74] Source: Marc Wauthelet.

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Bangladesh Agricultural University was established as the only university of its kind in Bangladesh in 1961. It started functioning with the College of Animal Husbandry and Veterinary Science at Mymensingh as its nucleus. The university has six faculties and 43 departments covering all aspects of agricultural education and research. BAU was the second highest budgeted public university in Bangladesh for the year 2013–2014. It is ranked number one university of Bangladesh according to the webomertrics university ranking 2017. The Bureau of Socio-Economic Research and Training at BAU was established in 1977 at the BAU Faculty of Agricultural Economics & Rural Sociology to promote research, training and extension activities of the faculty staff. The Bureau conducts nationally and internationally funded research projects, while also provides research consultancy and advisement for Government and Non-Government Organisations. The Bureau publishes twice yearly *The Bangladesh Journal of Agricultural Economics*, in addition to reports and monographs based on the research projects completed by the faculty members.

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