Training Program on Sustainable Natural and Advance Technologies and Business Partnerships for Water & Wastewater Treatment, Monitoring and Safe Water Reuse in India

Horizontal Flow Wetland

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PAVITR

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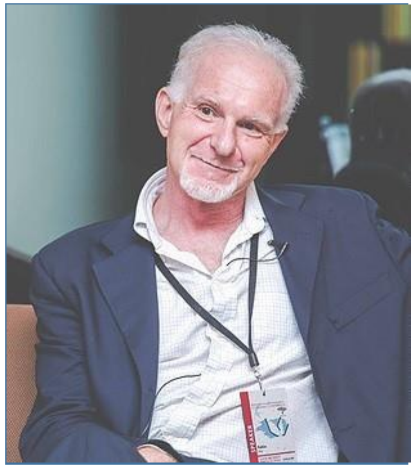
Introduction to the authors



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IRIDRA SRL

Iridra Srl founded in 1998, is a private consulting engineering firm composed by an interdisciplinary group of professionals with multi-annual experience in the water management and in wastewaters treatment with natural systems (Constructed Wetlands, CWs), where Iridra is recognized as the leader company in Italy and one of the most well-known in the world.

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Learning objectives

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At the end of this session, participants will:

- have more familiarity with horizontal flow constructed wetlands, their functioning and the involved biological processes
- have the preliminary skills for a first assessment and sizing of horizontal flow constructed wetlands
- know the preliminary basis for their construction and operation

Agenda of the session

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Time	Content
5 min	Introduction to the session
25 min	Introduction to the technology (background overview, principles, performance expected, appropriateness)
60 min	Design of the technology (key considerations, basic calculations, key formulas, etc.)
15 min	Break
15 min	Operation and maintenance
15 min	Construction and/or implementation
30 min	Example: the PAVITR pilot
12 min	Homework: exercise to design/implement the technology for a case study
13 min	Final remarks

Introduction to the technology

Horizontal subsurface flow (**HF**)

Constructed Wetlands

Horizontal subsurface flow CW

Description

Horizontal Flow (HF) wetlands are composed of one or more beds, filled with proper inert material, and pre-treated wastewater flows horizontally through a planted filter bed. Wastewater flows below the surface, maintaining continuous saturated conditions.

HF scheme

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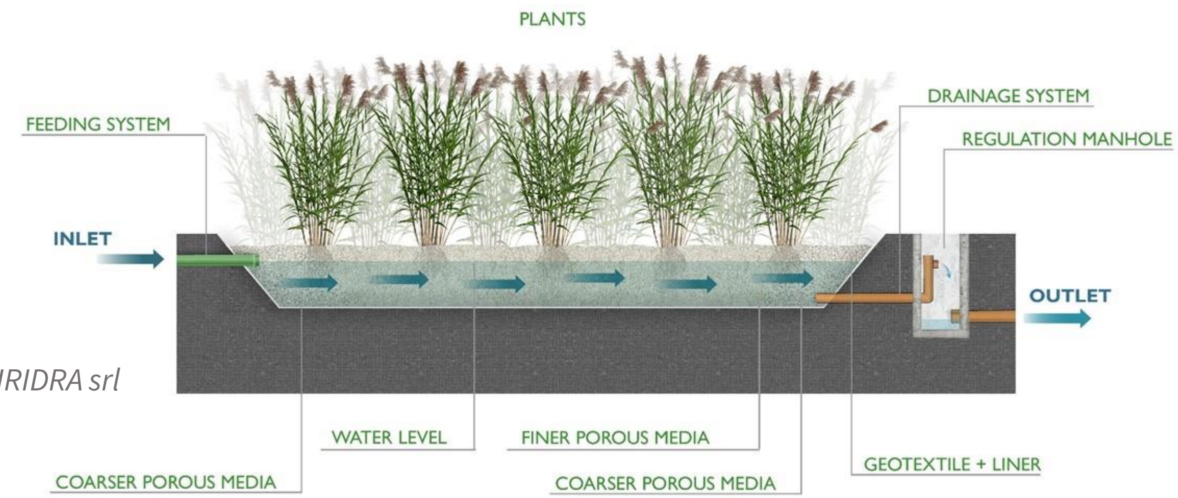
Horizontal subsurface flow CW

- They consist of gravel beds (40 to 80 cm deep) planted with wetland vegetation
- They are typically designed to treat primary effluent prior to soil dispersal or surface water discharge
- They are commonly used for secondary treatment for single-family homes, small cluster systems or small communities. However, they are also used for other several applications (e.g. wastewaters from industry)
- The wastewater stay beneath the surface media and flows in and around the plant roots and rhizomes. For that, there are no risks to expose humans and wildlife to pathogens and to provide a suitable habitat for mosquitoes
- This kind of CW is particularly efficient in suspended solids, carbon and pathogens removal, as well as for denitrification. Due to its prevalently anoxic conditions, nitrification is quite limited

Horizontal subsurface flow CW

Horizontal Flow (HF) wetlands are secondary treatment facilities for household, municipal, or industrial wastewater, and can also be used as a tertiary treatment system for polishing. HFs are planted with emergent aquatic macrophytes, which provide a suitable environment for microbiological attachment, aerobic biofilm growth and oxygen transfer to the root zone. Organic matter and suspended solids are mainly removed by filtration and microbiological degradation in prevalently anoxic conditions.



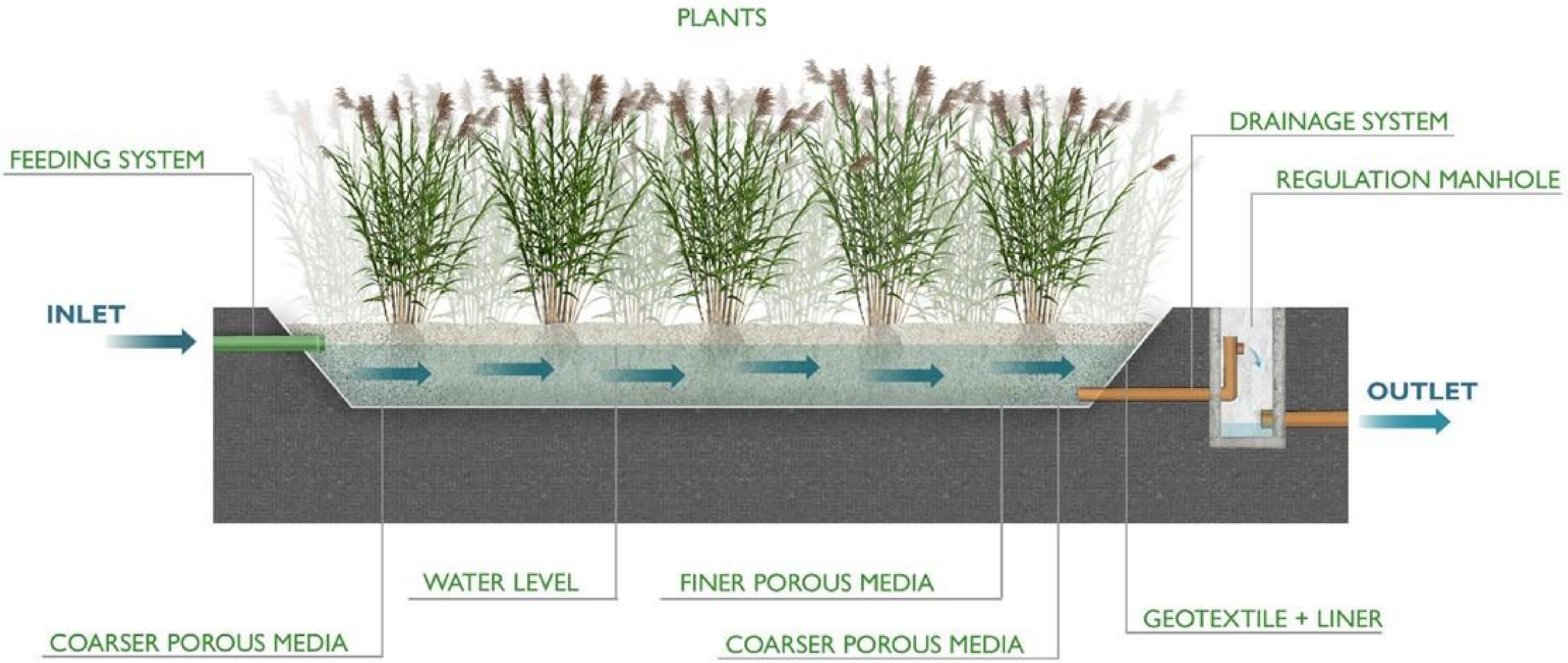
Source: IRIDRA srl

Horizontal subsurface flow CW

HF wetlands are typically comprised of :

- Inlet piping
- A clay or synthetic (HDPE or PVC) liner
- Filter media: the bed filling material is sized to offer an appropriate hydraulic conductivity (the most used media are coarse gravel, fine gravel and coarse sand) and to furnish a large available surface for the bio-film growing. In the inlet and outlet zones is advised to use large filling material, like as stones, in order to ensure an easy cleaning if clogging happens
- Emergent vegetation (e.g. Phragmites australis)
- Berms
- Outlet piping with water level control

Horizontal subsurface flow CW



Source: IRIDRA srl

Horizontal subsurface flow CW

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- In general, HF wetlands have been utilized for smaller flow rates than FWS wetlands, probably because of cost and space considerations
- They are generally more expensive than FWS wetlands, even if the maintenance and operating costs remain low compared to alternative technologies
- A key operational consideration on these type of CWs is the propensity for clogging of the media. This situation can be caused by an erroneous prevision of the wastewater quantity distributed in the time, an insufficient distribution of the inlet flux, an inappropriate choice of the medium type in the inlet area and/or in the whole system or wrong geometry

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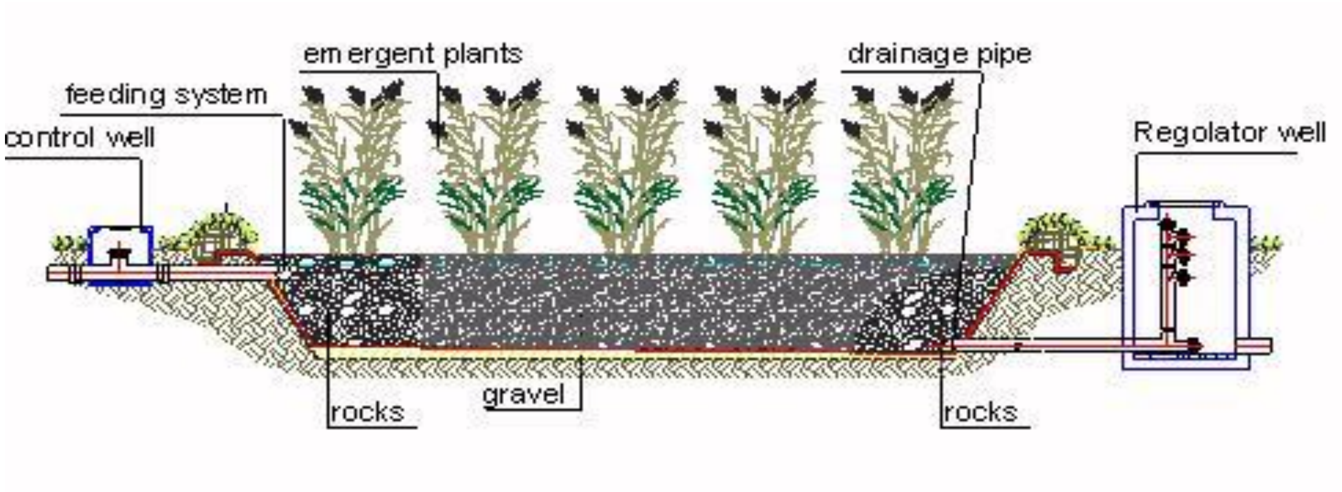
Horizontal subsurface flow CW



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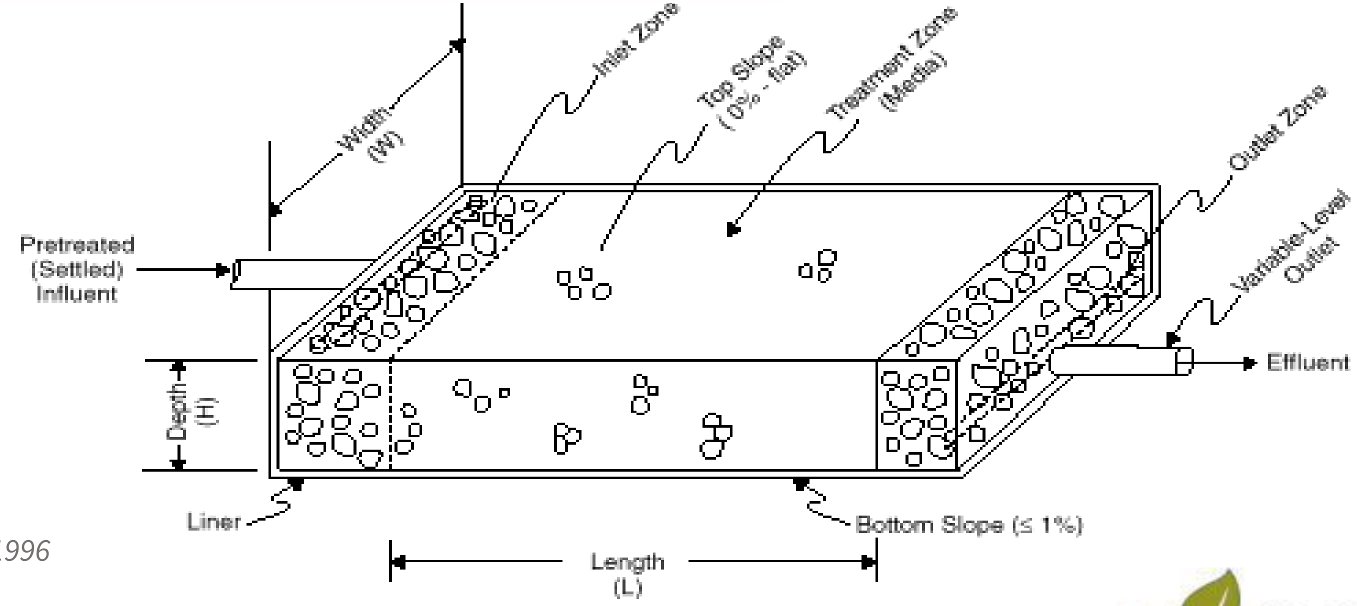
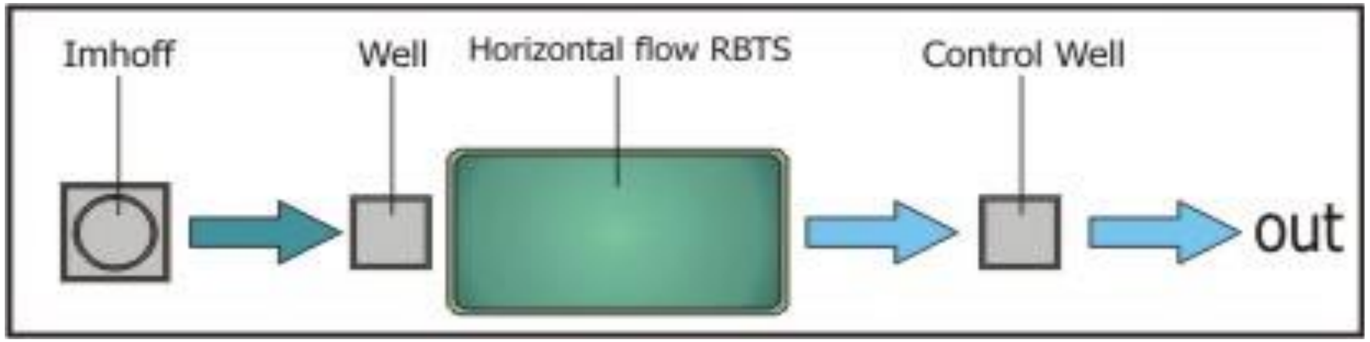
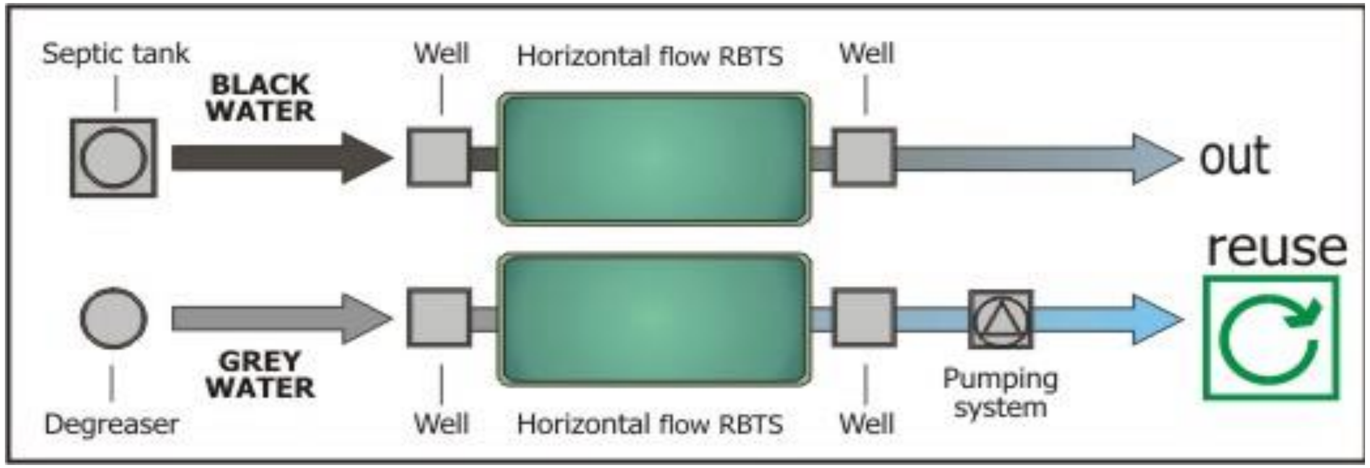


Source: Kadlec&Knight, 1996

Common configurations





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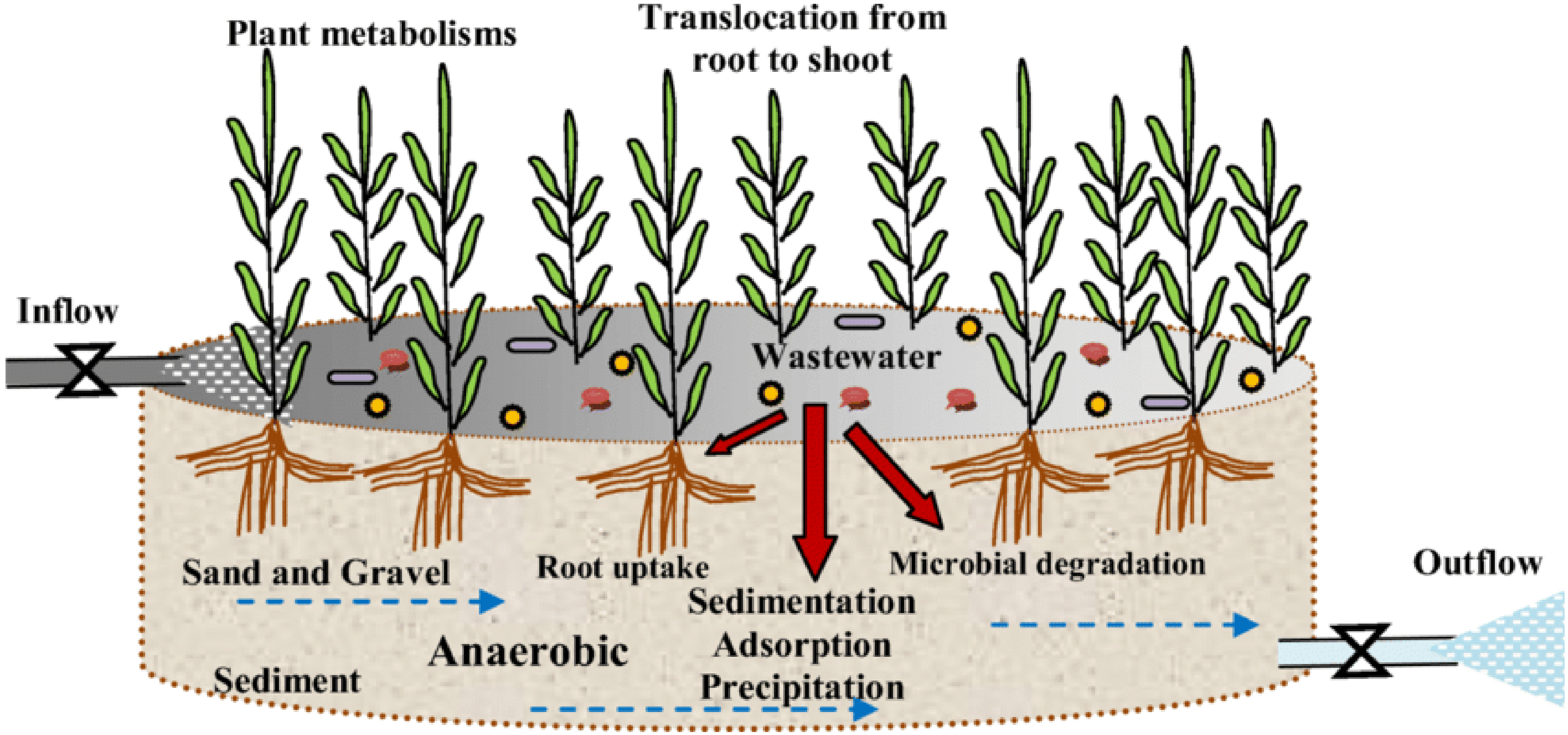
Removal mechanisms



Source: Ilyas, Huma & van Hullebusch, Eric. (2020).

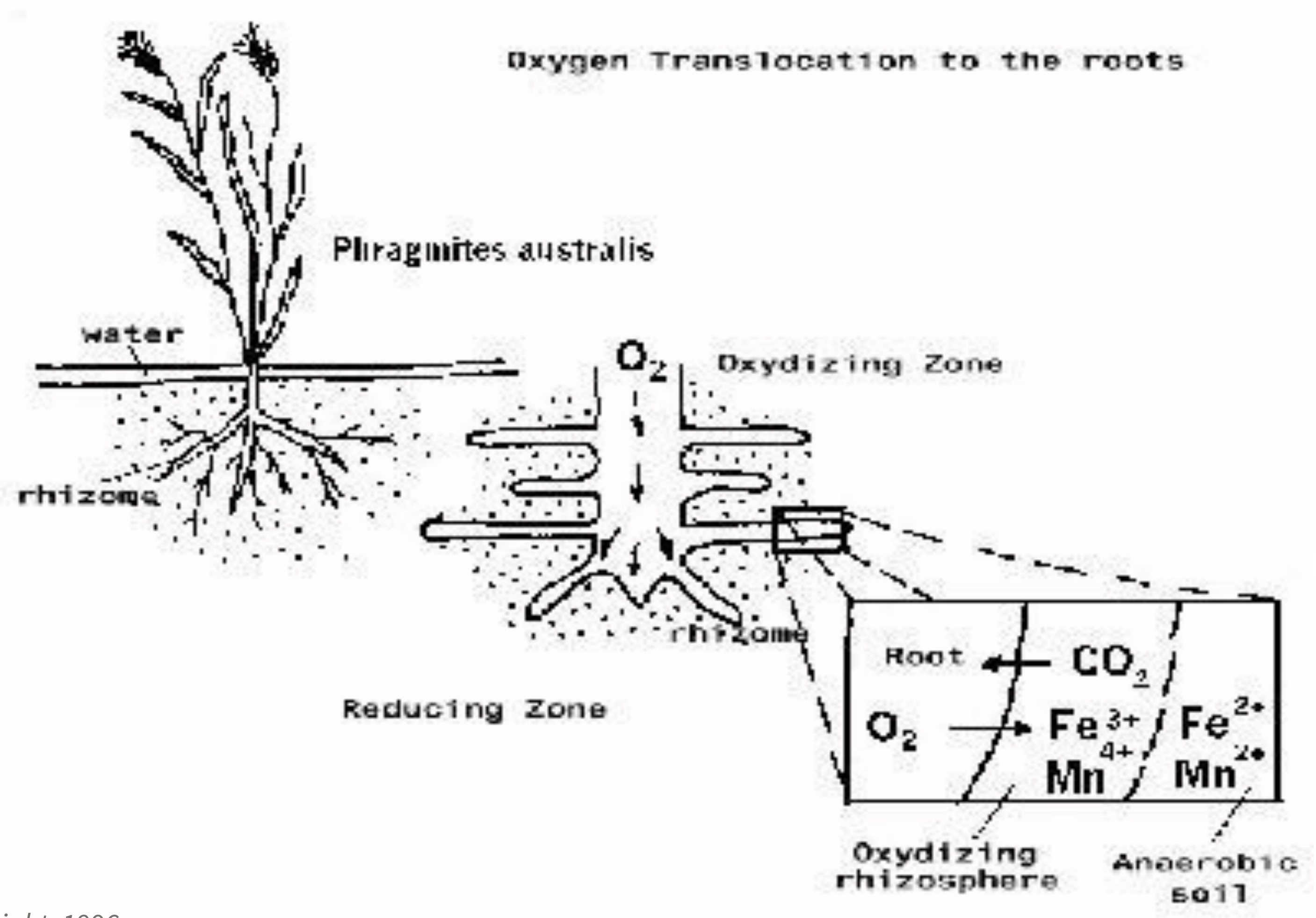
Removal mechanisms

Pollutants	Removal mechanism
Organic matter (measured as BOD)	Aerobic and anaerobic degradation
Organic micro-pollutants (e.g. pesticides, trichlorethan, chloroform, etc.)	Adsorption Sedimentation Volatilization Evaporation Photosynthesis Biotic/abiotic degradation
Suspended solids	Sedimentation Filtration/adsorption
Nitrogen	Ammonification-nitrification-denitrification Root uptake Adsorption (absorption in the substrate) Ammonia volatilization
Pathogenic micro-organisms	Sedimentation Filtration Predation UV degradation Adsorption Die-off Action of antibiotics released by roots

The role of plants

- **Physical effects**: roots provide surface area for attached micro-organisms; root growth maintains the hydraulic properties of the substrate; vegetation cover protects the surface from erosion and shading prevents algae growth; Litter provides an insulation layer on the wetland surface (especially for operation during winter).
- **Uptake**: 1) nutrients: plays a minor role for common wastewater parameters compared to the degradation processes by micro-organisms. 2) heavy metals and special organic compounds: different plant species can play a major role to enhance the treatment efficiency.
- **Release**: plants not harvested release during decomposition; Some plants: release of organic compounds (which can be used for denitrification) or oxygen (e.g. reeds – but too little compared to O2 demand of wastewater).
- other functions not directly related to the treatment process

The role of plants



Source: Kadlec&Knight, 1996

Design of **the technology**

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General CW Design

General CW Design criteria

In designing constructed wetlands, the aim is to maximize contact between the polluted water column and the various wetland components (biofilms, plants, the sediment layer, etc.). Contact efficacy depends on the water flow path in the system, that is related to the bed size and the residence time.
It is not advisable the use of simplistic guidelines for all situations. CWs must be individually designed for a particular set of objectives and constraints.

Horizontal flow system for 120 P.E. in Central Italy, operating since 2003

Source: IRIDRA srl

General CW Design criteria

- Hydrology
- Hydraulic Retention Time
- Hydraulic Loading Rate
- Filling Media (porosity, hydraulic conductivity kf)
- Redox conditions (aerobic, anaerobic, mix reactor)
- Geometry of the bed
- Waterproofing
- Inlet and Oulet devices
- Cells configuration (series and/or parallel)
- Choice of macrophytes
- Treatment goals (in terms of specific pollutants overall removal)

General CW Design criteria

Decisional tree: STEP 1

Determination of treatment goals

- End users analysis and characterization of wastewater to be treated (oxygen demand, suspended solids, organic content, nitrogen, pathogens, etc.)
- Individuation of the final discharge of treated water (e.g. superficial water, soil, reuse, etc.)
- Local regulations
- Determination of the level of requested treatment

General CW Design criteria

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Decisional tree: STEP 2

Choice of the most appropriate solution

- Does the constructed wetland technology fit with the objective of treatment ?
- Evaluation of project alternatives in terms of performances and technical-economic sustainability

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General CW Design criteria

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Decisional tree: STEP 3

Preliminary sizing

- Individuation of the most appropriate system design
- Outlined sizing of requested surface

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General CW Design criteria

Decisional tree: STEP 4

Identification of the intervention area

- Analysis of intervention area morphology
- Compatibility with the existing restrictions (the main restriction is usually represented by the space availability)
- Environmental impact evaluation

General CW Design criteria

Decisional tree: STEP 5

System design

- Choice of the adequate pre-treatment systems
- Choice of filling medium
- Choice of the plants
- Determination of the useful surfaces
- Geometry and configuration of the beds
- Choice of the waterproofing types
- Verification of the system performances
- Constructive parameters

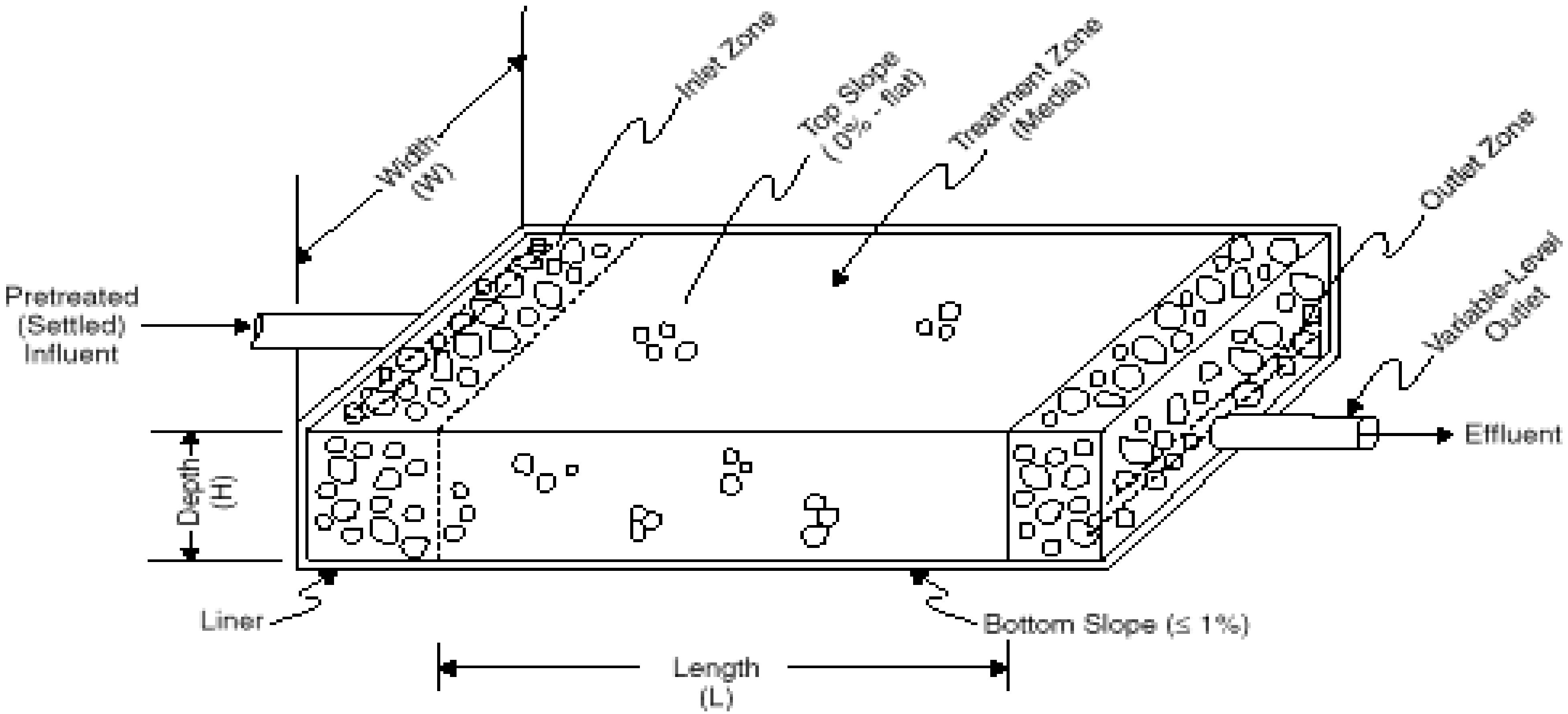
HF Design

HF Design

In HF systems, the wastewater is fed at the **inlet zone**, usually by gravity, and flows horizontally through the porous filter medium, remaining under the surface of the bed and without any contact with the atmosphere, until it reaches the **outlet** zone.

- **Pre-treatment** to avoid clogging
- **Plastic liner** to avoid soil contamination
- **Filter bed** about 2-5 m^2/p.e.; depth: 60-80 cm; bottom slope: 0.5-1%; length ≤ 25-30 m.
- **Hydraulic retention time (HRT):** 2-5 days
- **Hydraulic loading rate (HLR):** 60-80 mm/d for greywater; 30-60 mm/d for mixed wastewater.
- **Removal**: BOD: 80-90%, TSS: 80-95%, TN: up to 60%, FC: 2-4 log.

HF Design



Source: Kadlec&Knight, 1996

HF Design

Design criteria: hydrology

Factors affecting hydrology are:

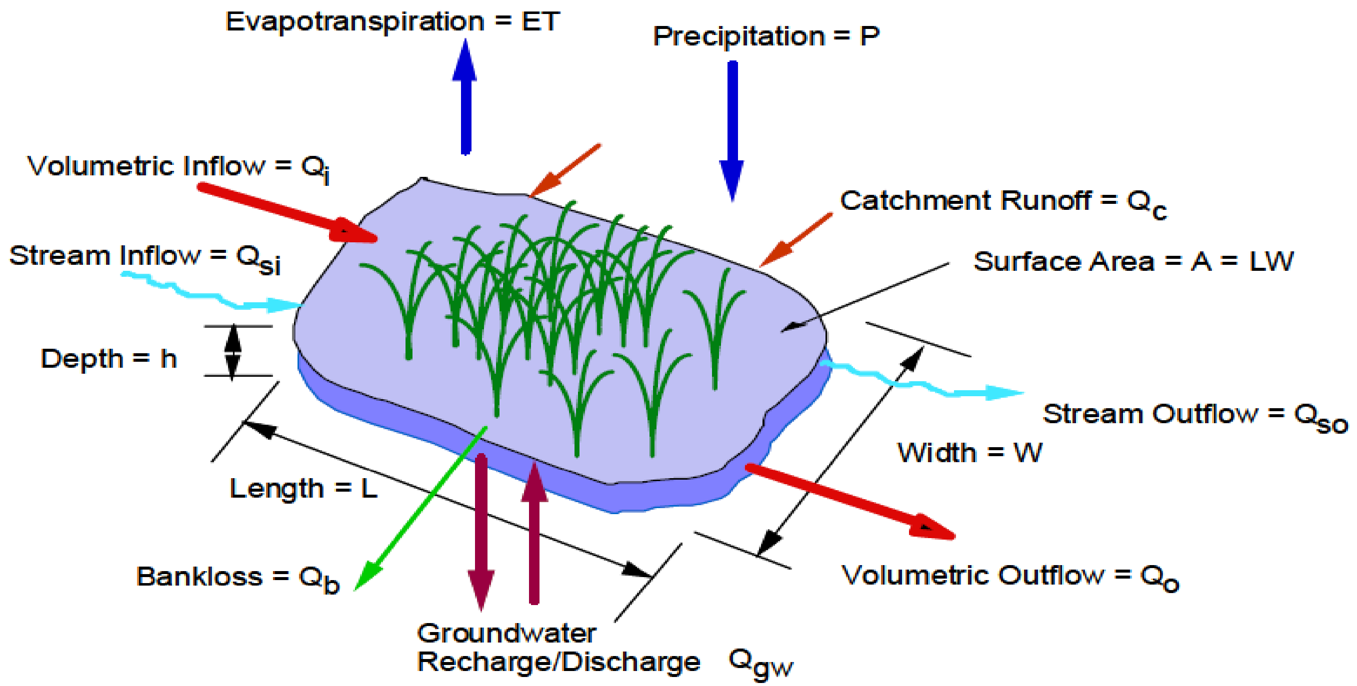
- Rainfall
- Infiltration
- Evapo-transpiration
- Hydraulic loading
- Filling medium
- Water depth

These factors can affect the organic matter and nutrient removal by varying both residence times and concentration of wastewaters to be treated

HF Design

Design criteria: hydrology

Water mass balance components in a CW



Source: IWA, 2000 (adapted)

Inlet Hydraulic Loading Rate = $Q_i/A = q_i$	HLR
Inlet Hydraulic Retention Time = $Aeh/Qi = t_i$	HRT

HF Design

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Design criteria: hydrology

Water mass balance components in a CW:

$$Q_i - Q_o + Q_c - Q_b - Q_{gw} + Q_{sm} + PA - EA = dV/dt$$

A	= wetland top surface area, m^2
E	= evapotranspiration rate, m/d
P	= precipitation rate, m/d
Q_b	= bank loss rate, m^3/d
Q_c	= catchment runoff rate, m^3/d
Q_{gw}	= infiltration to groundwater, m^3/d
Q_i	= input wastewater flowrate, m^3/d
Q_o	= output wastewater flowrate, m^3/d
Q_{sm}	= snowmelt rate, m^3/d
t	= time, d
V	= water storage in wetland, m^3

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HF Design

Design criteria: hydrology

Water mass balance components in a CW (simplified):

$$\boxed{Q_o = Q_i + PA - EA}$$

A	= wetland top surface area, m^2
E	= evapotranspiration rate, m/d
P	= precipitation rate, m/d
Q_i	= input wastewater flowrate, m^3/d
Q_o	= output wastewater flowrate, m^3/d

HF Design

Design criteria: HRT - hydraulic retention time

- Retention times can vary, but values below 24 hours are not suggested for HF (usually 2-5 days)
- It is important to maximize the contact of wastewater with the substrate (filling medium and plants) in which the bacteria biofilms develop
- The contact efficiency is in relation to water passage in the system, which in turn is linked to sizing and retention time
- Planning must aim at optimizing theoretical retention time and guarantee its fitting to real retention time

HF Design

Design criteria: HRT - hydraulic retention time

Factors affecting hydraulic retention time are:

- Vegetation
- Bed area and shape
- Flow rate
- Media porosity

HF Design

Design criteria: HRT - hydraulic retention time

$$\tau = \frac{\text{Liquid volume}}{\text{Flow}} = \frac{\varepsilon V}{Q_i} = \frac{\varepsilon h A}{Q_i}$$

where:

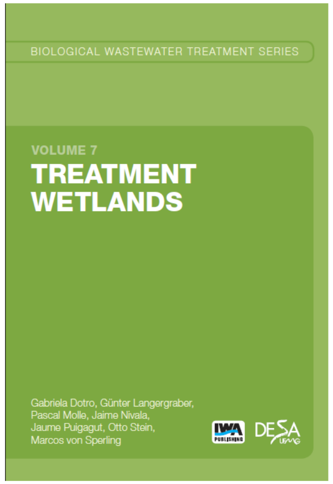
τ = nominal (theoretical) hydraulic retention time, d

ε = porosity (fraction of wetland volume occupied by water), unitless

h = wetland water depth, m

A = wetland surface area, m^2

Q_i = influent flow rate, m^3/d



HF Design

Design criteria: HLR - hydraulic loading rate

- It represents the more complex planning criteria because of its dependence on daily and seasonal variations linked to the end-user typology, climatic conditions, rainfall pattern, surface water and/or groundwater infiltrations
- A correct planning of hydraulic loading rate (HLR) is recommended to ensure long-term performance with no clogging
- Its is strictly linked to the hydrological factors of the site on which the constructed wetland is realized (climatic conditions, medium conductivity, organic loading, etc.)
- It is fundamental to know the characteristics of the inlet effluent (more specifically its pollutant loading)
- Where the probability of loading variation is high, the subsurface beds are frequently disposed in parallel.

HF Design

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Design criteria: filling media

- The medium is fundamental to guarantee the depurative performances since, besides providing a support for vegetation, it acts as mechanical and chemical filter for some substance contained in the wastewater.
- The medium choice depends on the characteristics of the wastewater to be treated
- To avoid clogging phenomena, the filling medium choice is oriented towards clean and washed gravel material (**NO SOIL**)
- To identify the most suitable mix, porosity and hydraulic conductivity tests, as well as the calculation of granulometric curve, are usually performed
- Bed depth is linked to the maximum root development in depth of the plant species chosen

HF Design

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Design criteria: filling media

- In HF systems it is necessary to assure a hydraulic conductivity **at least of 100 m/d**
- It is important to consider in planning that, during system functioning, the medium is enriched of microorganism, suspended solids and organic particulate. This determines an increase in medium size and, consequently, a reduction of empty spaces and hydraulic conductivity
- In HF systems, gravel with a average diameter in the range from **5 to 25 mm** are commonly used, depending by design, wastewater characteristics, bed shape, peak flow final goals. It is also advisable to use crushed rocks with a diameter of 80-120 mm in the first meter of inlet section to avoid clogging phenomena
- In HF systems, the granulometry is generally the same for the saturated zone to avoid the creation of preferential ways of wastewater flow and, consequently, the reduction of retention time; modifications in grain dimensions can eventually be accepted only along the longitudinal section in the same direction of the flow, providing larger grains in the initial sections and smaller in the final ones.
- In HF systems the medium depth varies, in dependence of the used vegetal

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HF Design

Design criteria: filling media

Characteristics of some filling media utilized in subsurface flow wetlands

Typology	Size (mm)	Porosity (%)	Hydraulic conductivity (Ks = m/d)
Sand (tertiary)	1-2	30-32	420-480
Gravel (secondary)	8-16	35-38	500-800
Crushed stones (inlet and outlet)	32-128	40-45	1200-1500

HF Design

Design criteria: filling media

Inlet zone

Outlet zone

Source: Jan Vymazal

Inlet and outlet filling medium in HSSF systems

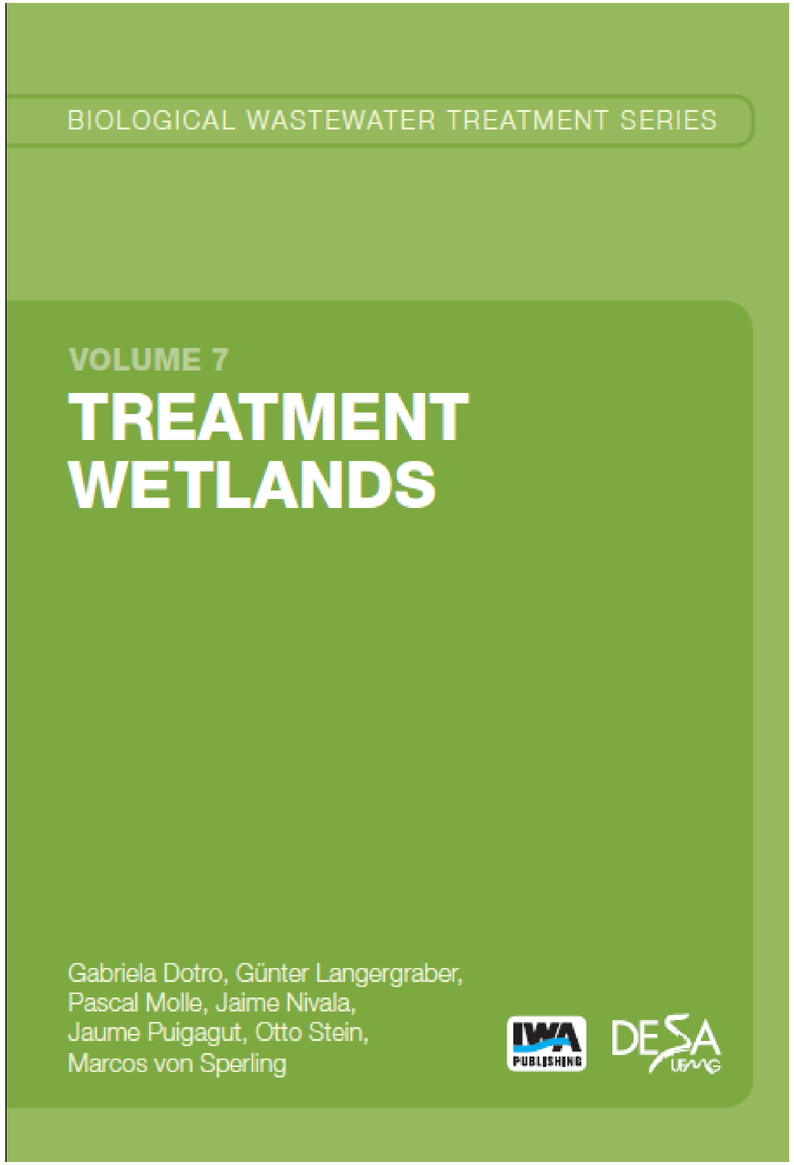
Inlet and outlet zones are filled with large stones in order to provide good water distribution along the inflow zone and good even collection of water along the outflow zone

HF Design

Design criteria: primary treatment

Operation/process	Application/occurrence	Particle size affected
Screening, coarse	Used to remove large particles such as sticks, rags and other large debris from untreated wastewater by interception	> 15 mm
Screening, fine	Removal of small particles	1.5-6.0 mm
Screening, micro	Removal of small particles	> 0.025 mm
Comminution	Used to cut up or grind large particles remaining after coarse screening into smaller particles of a more uniform size	6 mm
Gravity separation	Removal of settleable solids and floating material	> 0.040 mm
Grit removal	Removal of grit, sand and gravel	> 0.15 mm
Oil and grease removal	Removal of oil and grease from individual discharges	
Imhoff tank	Used for the removal of suspended materials from household wastewater by sedimentation and flotation	> 0.040 mm
Septic tank	Used for the removal of suspended materials from household wastewater by sedimentation and flotation	> 0.040 mm

Overview of sizing methods



Dotro, G., Langergraber, G., Molle, P., Nivala, J., Puigagut, J., Stein, O., & Von Sperling, M. (2017). Treatment wetlands (p. 172). IWA publishing.

- Rule of Thumb
- Empirical regression equations
- Kinetic plug-flow k-C* (Reed et al., 1995)
- Oxygen balance
- Loading charts (Kadlec and Wallace, 2009)
- Kinetic P-k-C* (Kadlec and Wallace, 2009)
- Numerical modelling

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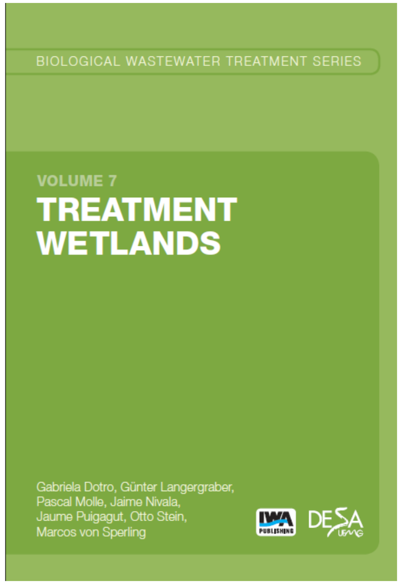
HF Sizing methods

Rule of Thumb

Table 2.7 Rule-of-thumb design recommendations for temperate climates.

Country	Technology	Specific surface area (m^2/PE)	Reference
Austria	VF	4	ÖNORM B 2505 (2009)
Denmark	HF	5	Brix and Johansen (2004)
	VF	3	
Germany	VF	4	DWA-A 262 (2017)
France	French VF	2	Iwema et al. (2005)



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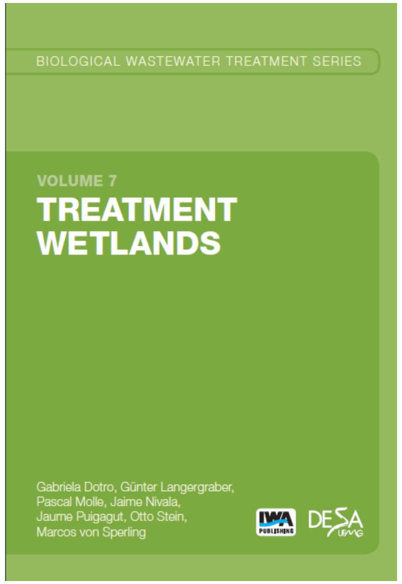
HF Sizing methods

Empirical regression equations

Table 2.8 Example regression equations for HF wetlands.

Parameter	Equation [a,b]	Input Range [a,b]	Output Range [a,b]	R^2
BOD_5	$M_o = (0.13 \times M_i) + 0.27$	$6 < M_i < 76$	$0.32 < M_o < 21.7$	0.85
	$C_o = (0.11 \times C_i) + 1.87$	$1 < C_i < 330$	$1 < C_o < 50$	0.74
COD	$M_o = (0.17 \times M_i) + 5.78$	$15 < M_i < 180$	$3 < M_o < 41$	0.79
TSS	$M_o = (0.048 \times M_i) + 4.7$	$3 < M_i < 78$	$0.9 < M_o < 6.3$	0.42
	$C_o = (0.09 \times C_i) + 0.27$	$0 < C_i < 330$	$0 < C_o < 60$	0.67
TN	$M_o = (0.67 \times M_i) - 18.75$	$300 < M_i < 2{,}400$	$200 < M_o < 1{,}550$	0.96
TP	$M_o = (0.58 \times M_i) - 4.09$	$25 < M_i < 320$	$20 < M_o < 200$	0.61
	$C_o = (0.65 \times C_i) + 0.71$	$0.5 < C_i < 19$	$0.1 < C_o < 14$	0.75

[a] M_i and M_o are mass loads into and out of the system, respectively, in kg/ha·d (Vymazal, 1998).
[b] C_i and C_o are concentrations into and out of the system, respectively, in mg/L (Brix, 1994).



Dotro, G., Langergraber, G., Molle, P., Nivala, J., Puigagut, J., Stein, O., & Von Sperling, M. (2017). Treatment wetlands (p. 172). IWA publishing.

HF Sizing methods

Kinetic plug-flow k-C*

$$A = \frac{Q_i}{k_A} \ln\left(\frac{C_o - C^*}{C_i - C^*}\right) \qquad (2.18)$$

where:

C_o = outlet concentration, mg/L

C_i = inlet concentration, mg/L

C^* = background concentration, mg/L

k_A = modified first-order areal rate coefficient, m/d

Q_i = influent flow rate, m^3/d

$$k_T = k_{20}\theta^{(T-20)} \qquad (2.14)$$

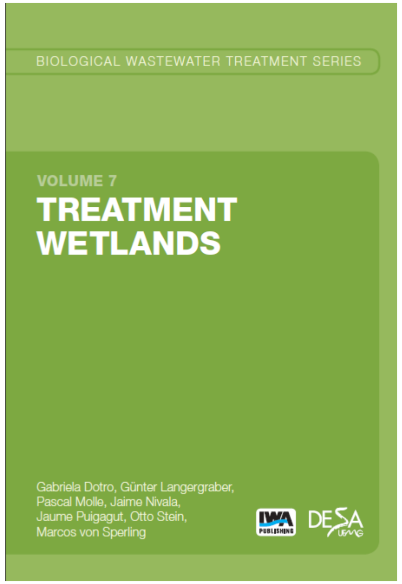
where:

k_T = rate coefficient at water temperature T

k_{20} = rate coefficient at water temperature 20°C

T = water temperature, °C

θ = modified Arrhenius temperature factor, dimensionless



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HF Sizing methods

Loading charts

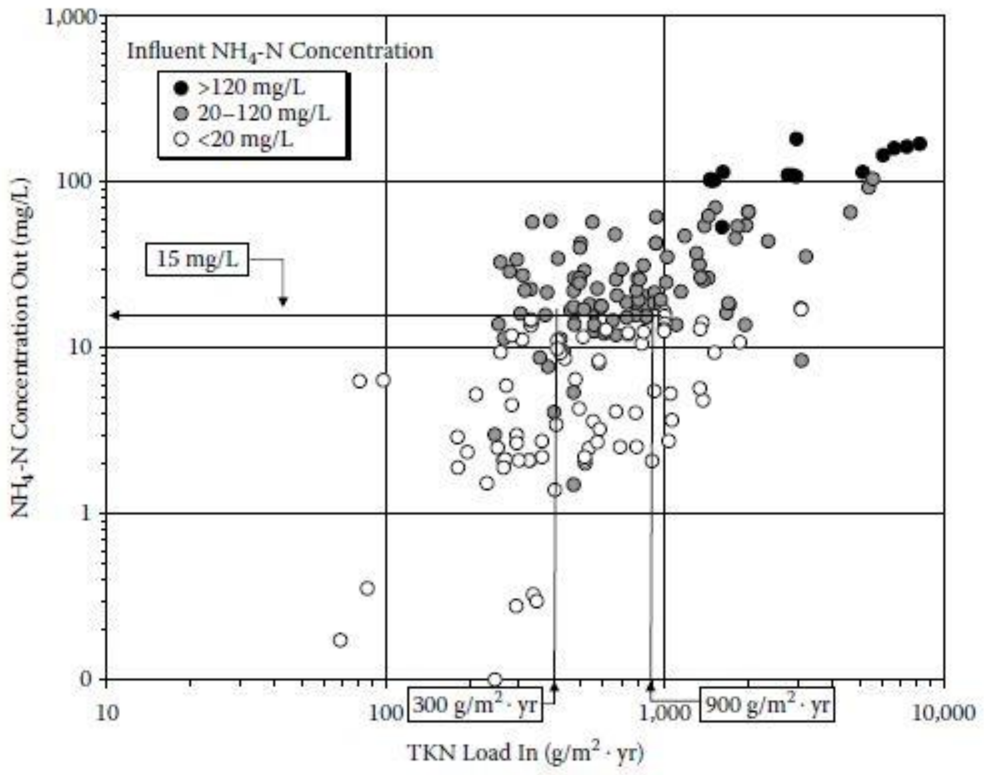
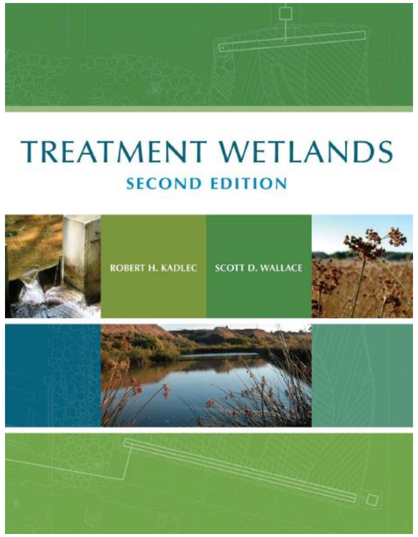


FIGURE 20.1 TKN–Ammonia loading chart, with forecasted treatment performance.



Kadlec, R. H., & Wallace, S. (2008). Treatment wetlands. CRC press.

HF Sizing methods

P-k-C*

$$A = \frac{PQ_i}{k_A}\left(\left(\frac{C_i - C^*}{C_o - C^*}\right)^{\frac{1}{P}} - 1\right) = \frac{PQ_i}{k_V h}\left(\left(\frac{C_i - C^*}{C_o - C^*}\right)^{\frac{1}{P}} - 1\right)$$

where:

C_o = outlet concentration, mg/L
C_i = inlet concentration, mg/L
C^* = background concentration, mg/L
h = wetland water depth, m
k_A = first-order areal rate coefficient, m/d
k_V = first-order volumetric rate coefficient, 1/d
P = apparent number of tanks-in-series (TIS), dimensionless
Q_i = influent flow rate, m^3/d

$$k_T = k_{20}\theta^{(T-20)}$$

where:

k_T = rate coefficient at water temperature T
k_{20} = rate coefficient at water temperature 20°C
T = water temperature, °C
θ = modified Arrhenius temperature factor, dimensionless

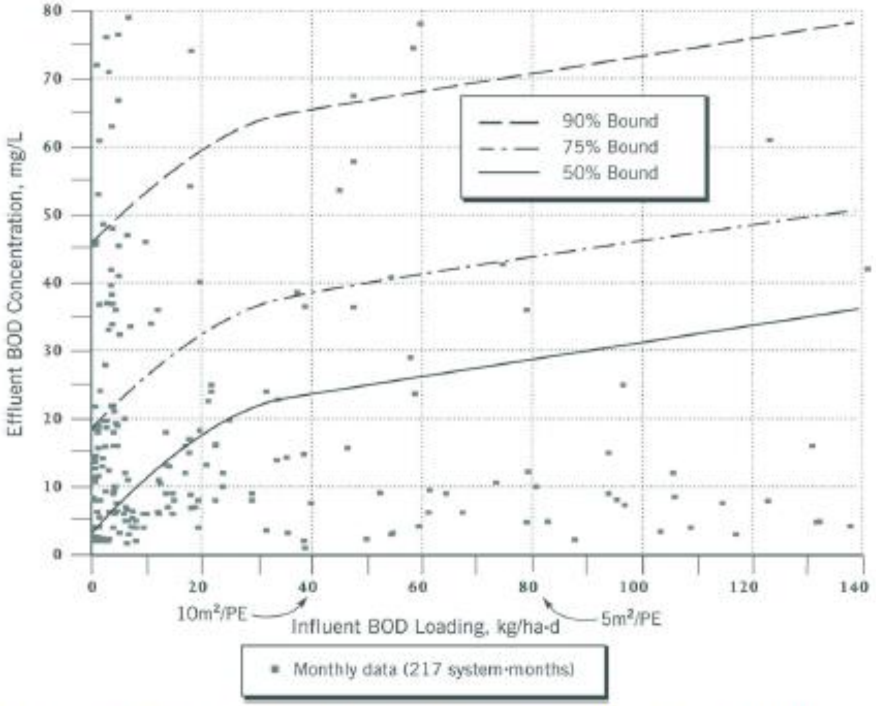
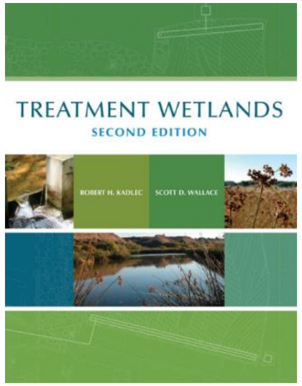


Figure 2.8 BOD_5 Loading chart for small-scale HF wetlands providing secondary treatment of domestic wastewater. Conversion to other loading units: 10 kg/ha·d = 1 g/m^2·d. Reprinted with permission from Wallace and Knight (2006).

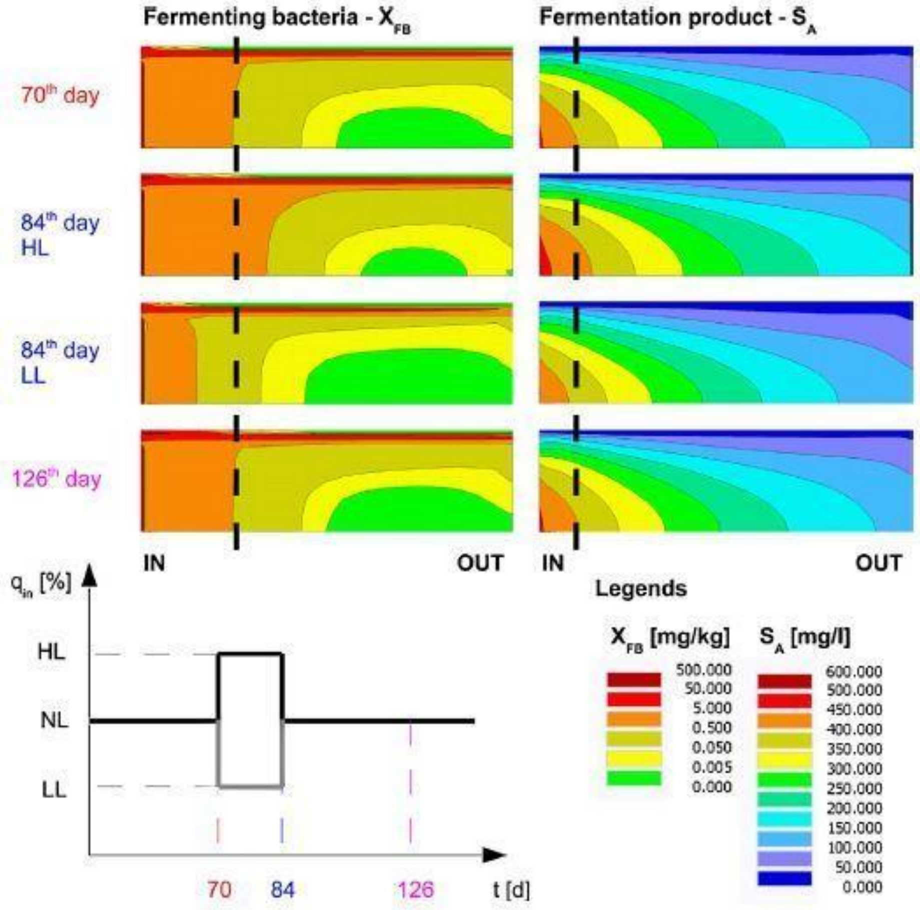


Kadlec, R. H., & Wallace, S. (2008). Treatment wetlands. CRC press.

HF Sizing methods

Numerical modelling

- HYDRUS Wetland Module
- BIOPURE



HF Checks

Hydraulic

The hydraulic regime of HSSF systems can be defined by the Darcy law in which the flux depends on the hydraulic conductivity of the filling media and the hydraulic gradient of the system.

The Darcy equation rules that the water flow is a function of the hydraulic conductivity (Ks), the cross area (A) and the slope of the bottom.

$$Q = K_s\ A\ S$$

Q = daily mean flow (m^3)
Ks = hydraulic conductivity of a unit surface orthogonal to flux direction (m/s)
A = cross area (m^2)
S = slope (hydraulic gradient)

HF Checks

Hydraulic

Applying the equation to the initial and final height of the bed (Hi and Hf), it is possible to verify if the chosen geometry is appropriate.

The bed bottom slope is designed in order to respect Darcy Law and permit to drain the incoming hydraulic load, maintaining the subsurface flow condition in all the possible management scenarios.

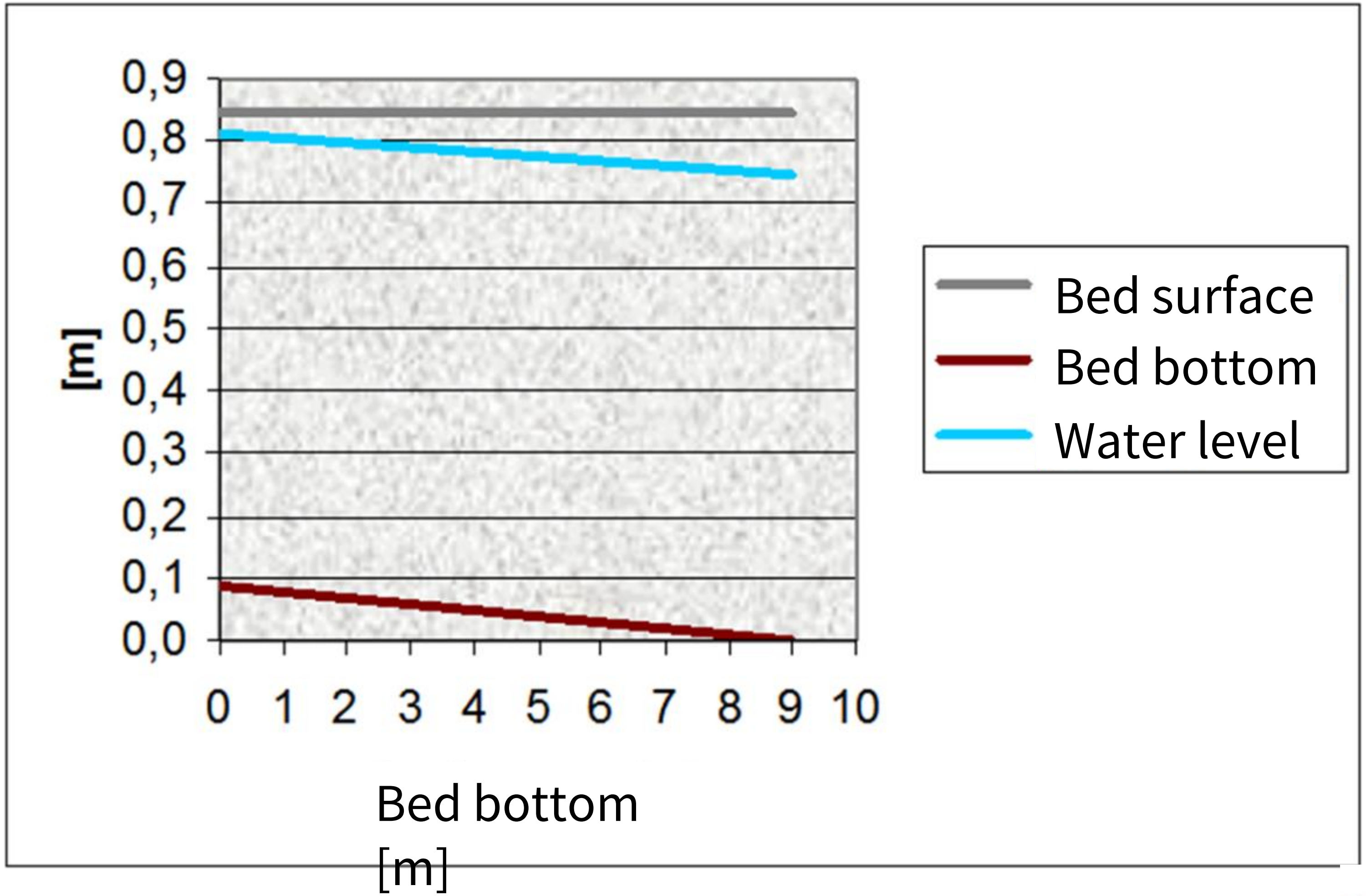
The bottom slope ranges from 1% to 5%.

$$H_i^2 = H_f^2 - \frac{2 \cdot L \cdot Q}{W \cdot K_S}$$

Hi = bed initial height (m)
Hf = bed final height (m)
Q = daily mean flow (m^3)
Ks = hydraulic conductivity (m/s)
W = cross section (m)
L = bed length (m)

HF Checks

Hydraulic



Source: *IRIDRA*

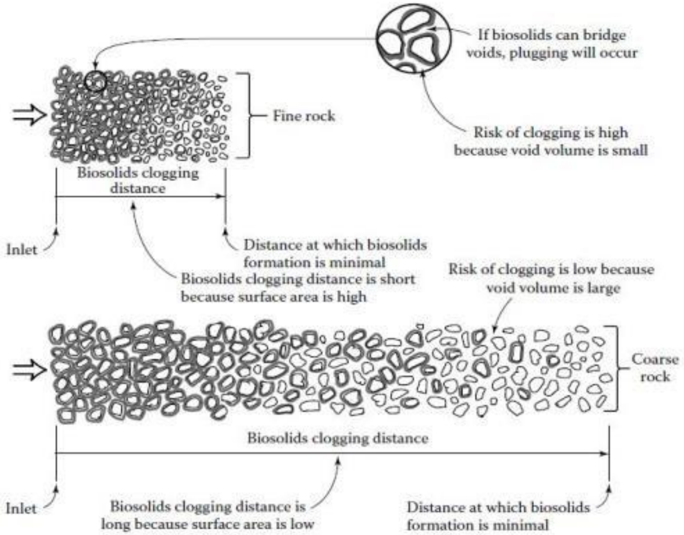
HF Checks

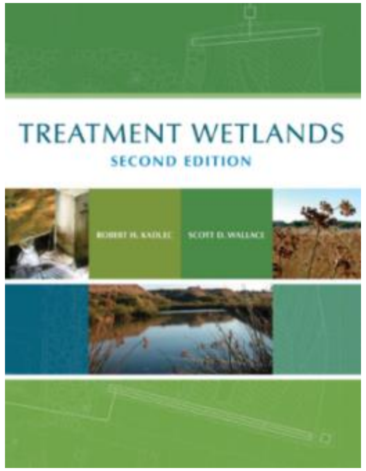
Clogging

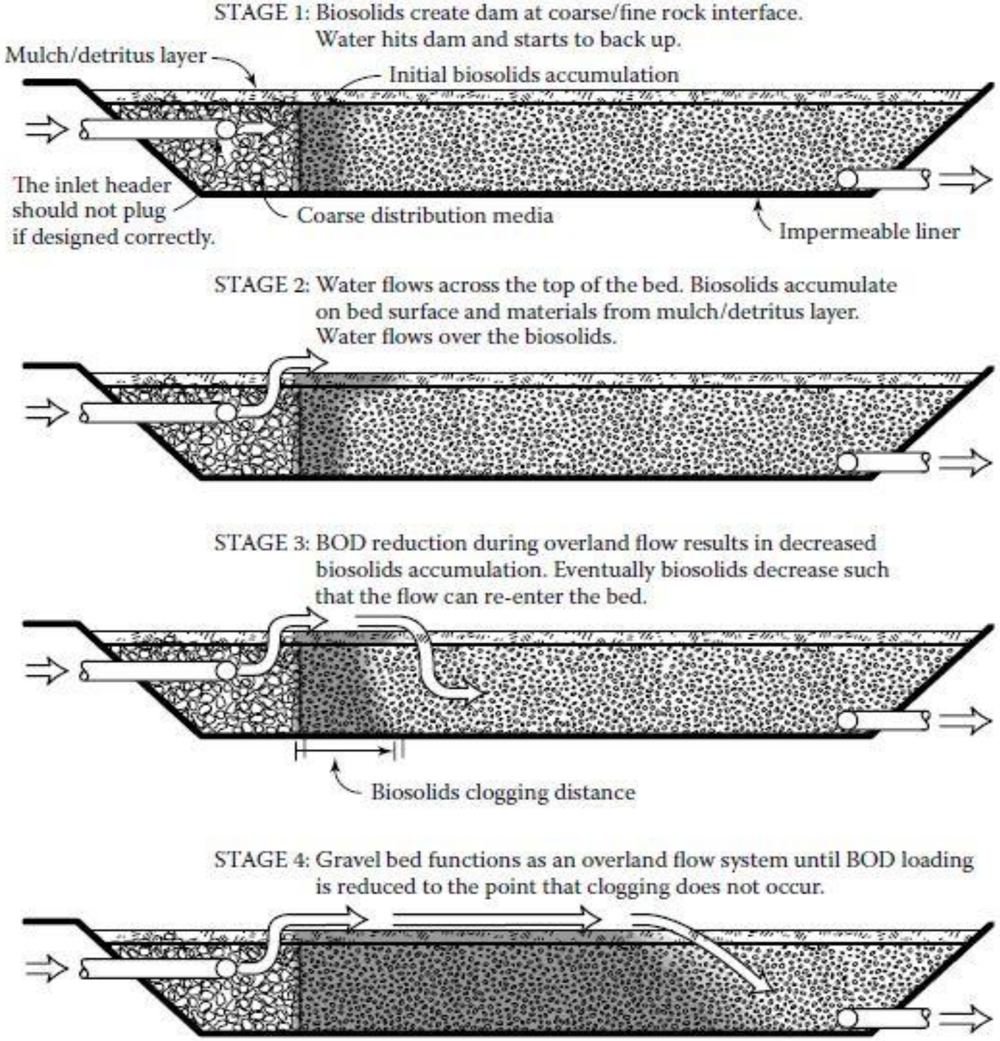
Source: IRIDRA

HF Checks

Clogging







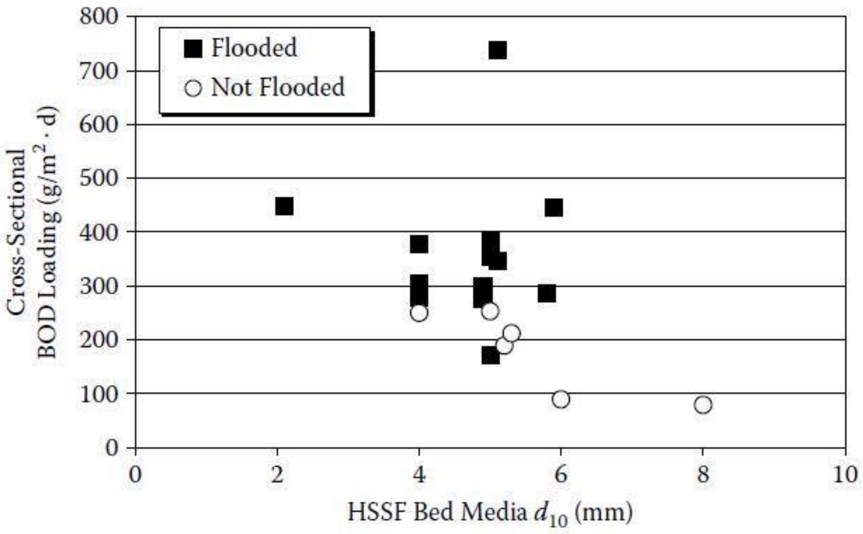
Source: R. Kadlec & S.D. Wallace, 2006

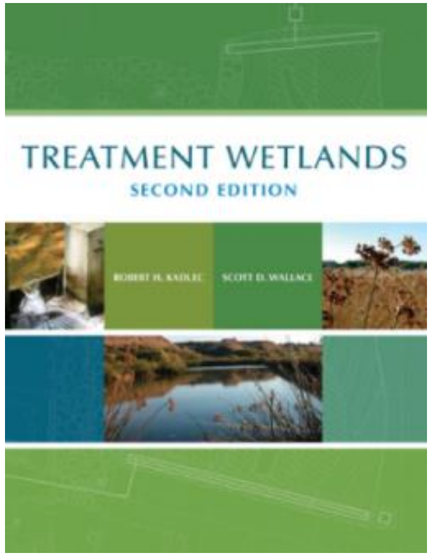
HF Checks

Hydraulic

Maximum cross-sectional loading rate (EPA)

- Max: 0,5 Kg BOD5/m2 per day
- OK: 0,2 Kg BOD5/m2 per day





Source: *R. Kadlec & S.D. Wallace, 2006*

Key learning points…

- HF wetlands: planted filter bed for wastewater treatment, horizontal subsurface flow
- Particularly efficient in suspended solids, carbon and pathogens removal and denitrification
- Components: inlet and outlet piping, waterproof liner, filter media, vegetation, berms
- Pre-treatment → primary treatment → HF CW → discharge/reuse

- Filter bed: about 2-5 m^2/p.e.; depth: 60-80 cm; bottom slope: 0.5-1%; length ≤ 25-30 m.
- Filter medium: gravel 10-20 mm
- HRT: 2-5 d
- HLR: 60-80 mm/d greywater; 30-60 mm wastewater
- OLR: ≤ 0.25 kg BOD/m2 of transversal section/day

Let’s have a break

We will be back in 15 min

Construction and implementation

HF implementation

Simple implementation

- Material easily available *in situ*
- Often few or no experience in constructed wetland implementation by the builder
- Need to guarantee easy operation and maintenance
- As few as possible electromechanical tools

HF implementation

Implementation phases

1. Earthmoving
2. Waterproofing
3. Filling beds
4. Construction details
5. Planting and starting phase

HF implementation

1. Earthmoving

- Area preparation: excavation and embankments
- Reed bed preparation: levelling and compacting of bottom and banks, preparation of inlet and outlet
- Excavation sections for concrete works
- Excavation sections for pipe placing
- Reshaping of the area
  - Final embankments
  - Rainwater drainage
  - Restoring existing profiles
  - Consolidation

HF implementation

1. Earthmoving

Site cleaning

Excavation and embankments

Source: IRIDRA

HF implementation

1. Earthmoving

Excavation and terracing

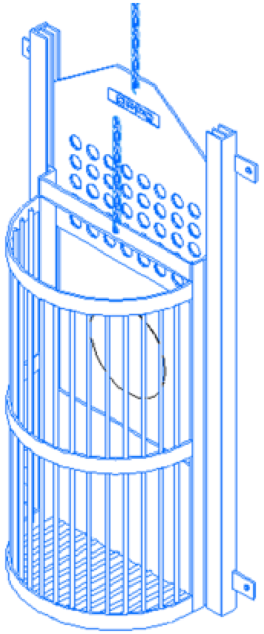
Excavation and embankments

Source: IRIDRA

HF implementation

1. Pre-treatment

Pretreatment – manually cleaned screening



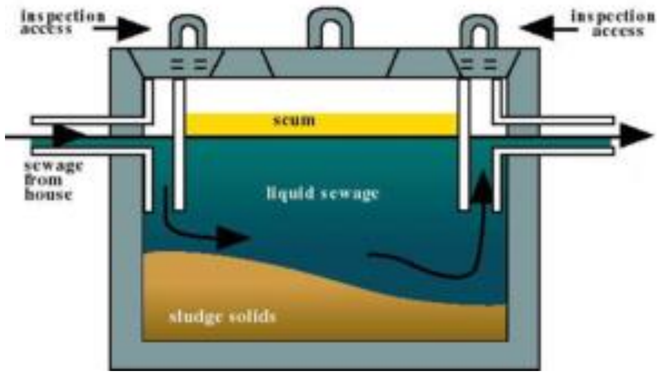
Pretreatment – mechanically cleaned screening

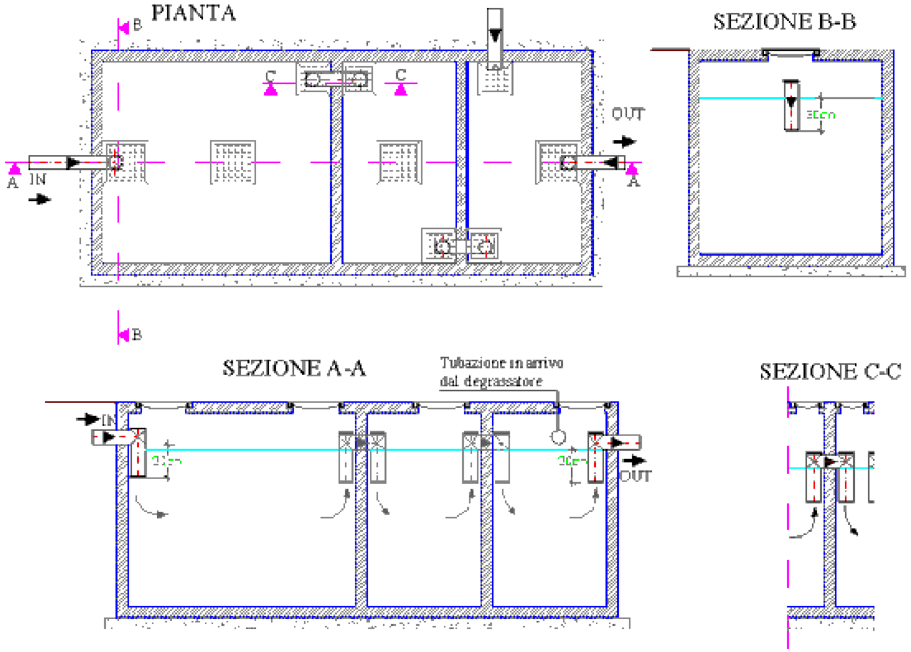
Source: IRIDRA

HF implementation

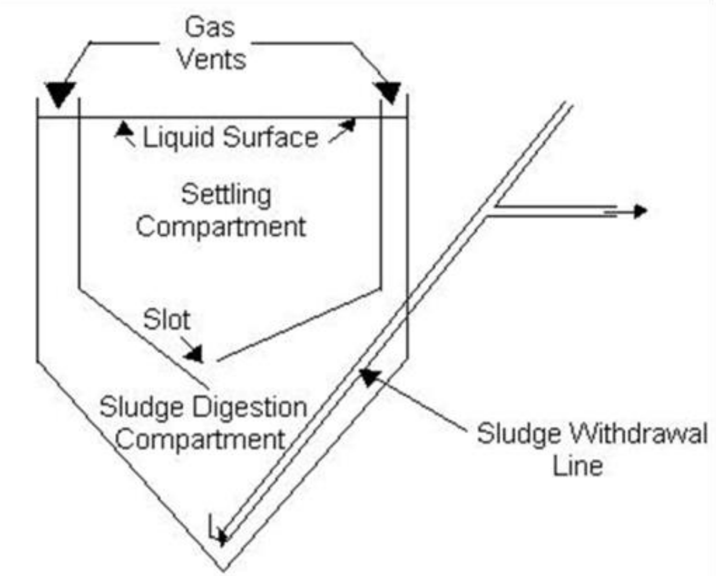
1. Primary treatment

Primary treatment - Septic tank





Primary treatment - Imhoff tank



Source: IRIDRA

HF implementation

1. Earthmoving

Excavation for concrete works

Reshaping of the area

Source: IRIDRA

HF implementation

2. Waterproofing

1st geotextile layer

Sand layer

Source: IRIDRA

HF implementation

2. Waterproofing

Geomembrane

2nd geotextile layer

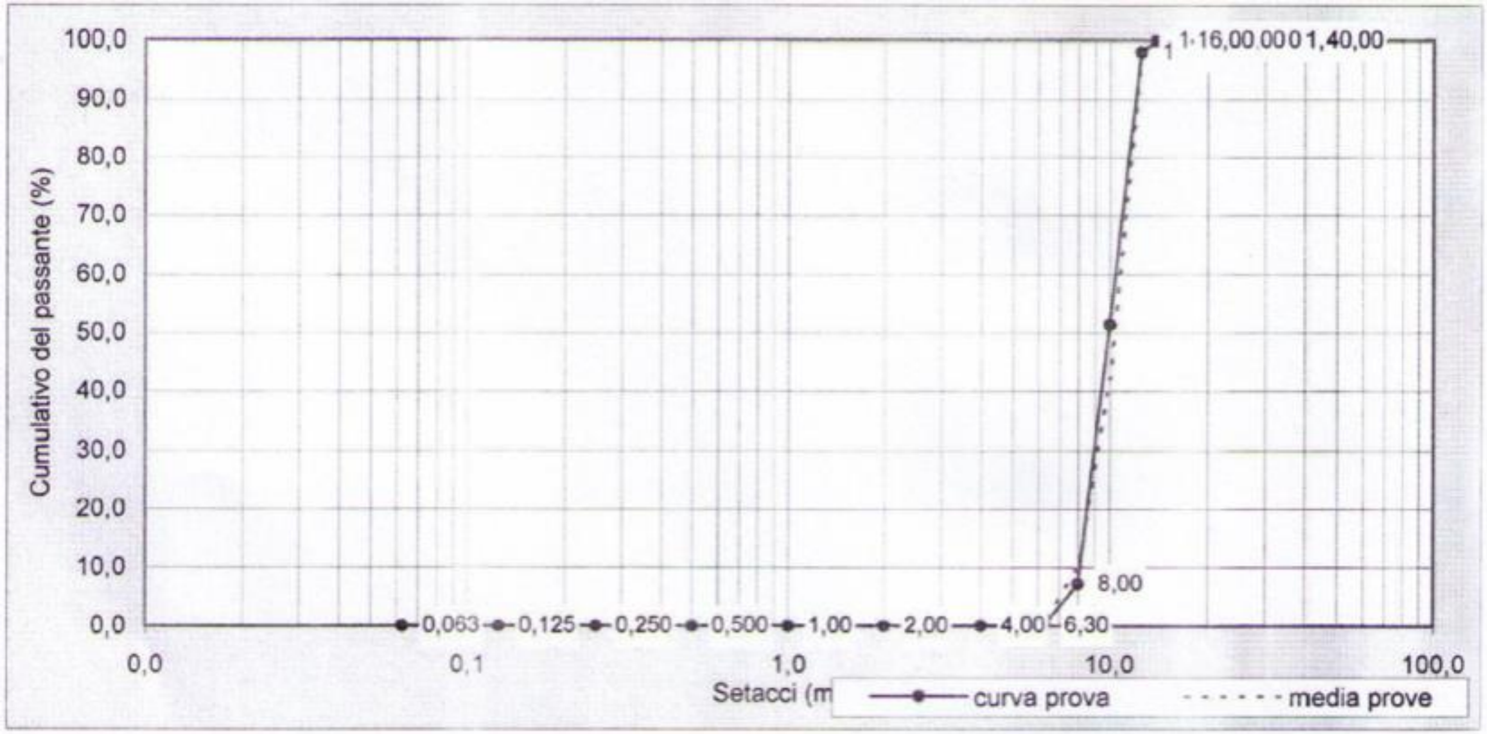
Source: IRIDRA

HF implementation

3. Filling beds

Recommendations:

- As much as possible according to literature indications
- Well cleaned
- Possible rounded grain (crushed material is also accepted)



Possible HF grain size distribution

HF implementation

3. Filling beds

Source: IRIDRA

HF implementation

4. Construction details

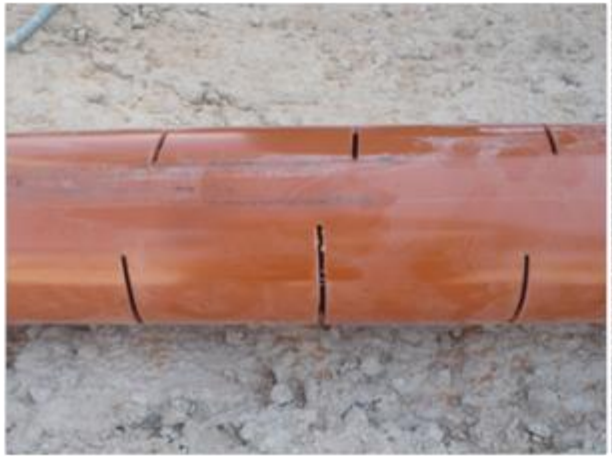
Feeding system

Source: *IRIDRA*

HF implementation

4. Construction details

Drainage



Source: IRIDRA

HF implementation

4. Construction details

Water table regulation

Source: IRIDRA

HF implementation

Plants

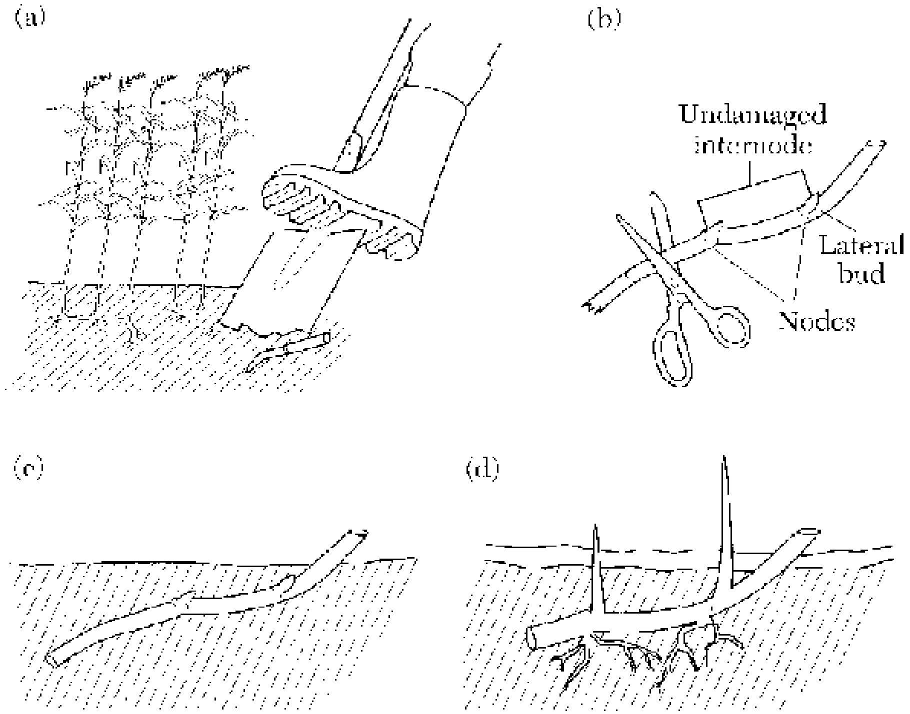
Plant species	Root depth (m)
Phragmites australis	0.7-0.8
Typha spp.	0.3-0.4
Schoenoplectus lacustris	0.8
Juncus spp.	0.6
Iris pseudacorus	0.3-0.4
Canna indica	0.3-0.4

In the HF systems it is necessary to know the root development in depth since the bed depth must be planned in function of this characteristic.

HF implementation

5. Planting and starting phase

Dig preparation for plants



Rhizom
e

Pot plants

Source: IRIDRA

HF implementation

5. Planting and starting phase

Bed flooding

Source: IRIDRA

Key messages

- Earthmoving: reed bed, piping, concrete tanks
- Pre-treatment and primary treatment
- Waterproofing: 1st geotextile layer, sand layer, geomembrana, 2nd geotextile layer
- Drainage system: slotted pipes
- Bed filling: clean, round gravel
- Feeding system
- Water table regulation device
- Vegetation: *Phragmites australis, Typha spp., Schoenoplectus lacustris, Juncus spp., Iris pseudacorus, Canna indica*
  - Dig preparation
  - Planting
  - Bed flooding

Source: IRIDRA

Operation and maintenance

HF Operation & Maintenance

O&M requirements for HF wetlands are relatively simple and can be conducted by unskilled labour after adequate training (no handling of high-tech appliances or chemical additives involved) which may allow a community organization or a private individual to manage the system. Maintenance includes:

- Periodic control and emptying of sludge and scum in the primary treatment system;
- Plant harvesting;
- Distribution system check ensuring that no clogging occurs in the bed;
- Sampling of the discharged water.

The water level should be maintained **5 – 10 cm** below the surface of the gravel to avoid odours and mosquito diffusion.

HF Operation & Maintenance

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Malfunctioning in the system

- Clogging of the medium or of the inlet and outlet devices
- No functioning of pumps or siphon if present
- Solid escape from primary treatment
- Hydraulic overload
- Solid overload
- Organic overload
- Incorrect plant management

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HF Operation & Maintenance

Malfunctioning in the system

Clogging

Source: IRIDRA

HF Operation & Maintenance

Example of O&M plan

Operation	Minimum frequency
1. Check of inlet and outlet device 2. Check of water level in HF system 3. Verification of the functioning of electro-mechanical tools 4. Check of the functioning of primary treatments 5. Check of weed and weeding during the first year from transplant in the HF system 6. Check of eventual bad odor	Every 30 days
Verification of system functioning by means of analysis of inlet and outlet flows	Monthly or seasonal
Check of sludge level in the primary treatment	Six-monthly
Plant cutting Sludge removal from primary treatment	Annual

Key messages

- Simple operation and management
- No high tech appliances
- No chemical additives
- Passive system
- Periodic control of inlet, outlet, water level
- Periodic sludge emptying from primary treatment
- Water level: 5-10 cm below surface
- Check for clogging
- Plant harvesting

Source: IRIDRA

Example:
the PAVITR pilot project

Effect of Irrigation with treated domestic wastewater on Vegetative Growth of Guava

Introduction

Objective

To analyze the effect of irrigation with treated domestic wastewater on growth and yield of guava

Location

The present research is conducted near the **Symbiosis International University, Lavale village, Pune, Maharashtra, India**

Anaerobic System and Constructed Wetlands :Location Map

Materials & Method

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Wastewater Treatment System

Domestic wastewater from the Symbiosis International University (n° students: **1600**) is collected at the **Sewage Treatment Plant** (STP); part of them are treated by a combination of artificial and natural treatment systems

Flow: 50-80 m^3/d depending on the pilot monitoring results

Total investment cost (CAPEX): 43,200.00 USD

STP

Anaerobic system (Anaerobic primary settler, baffled reactor and filter)

Constructed wetland (Horizontal Flow)

Tertiary treatment (U.V. and Dual Media Filter)

Reuse for irrigation

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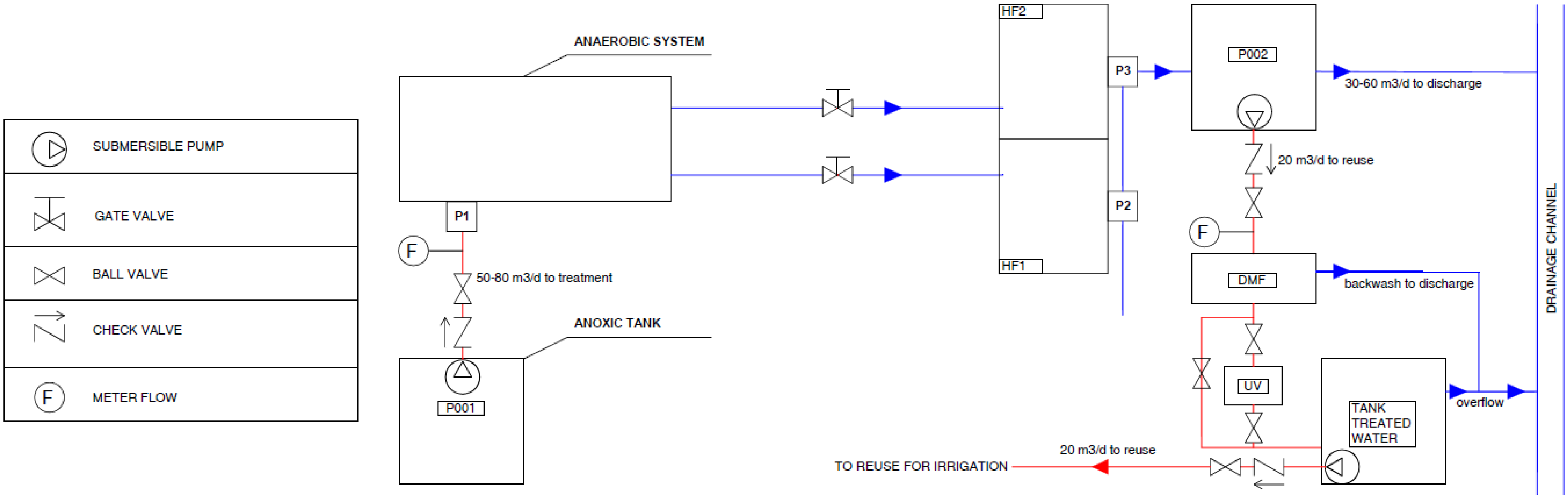
Materials & Method

Wastewater Treatment System - BFD



Materials & Method

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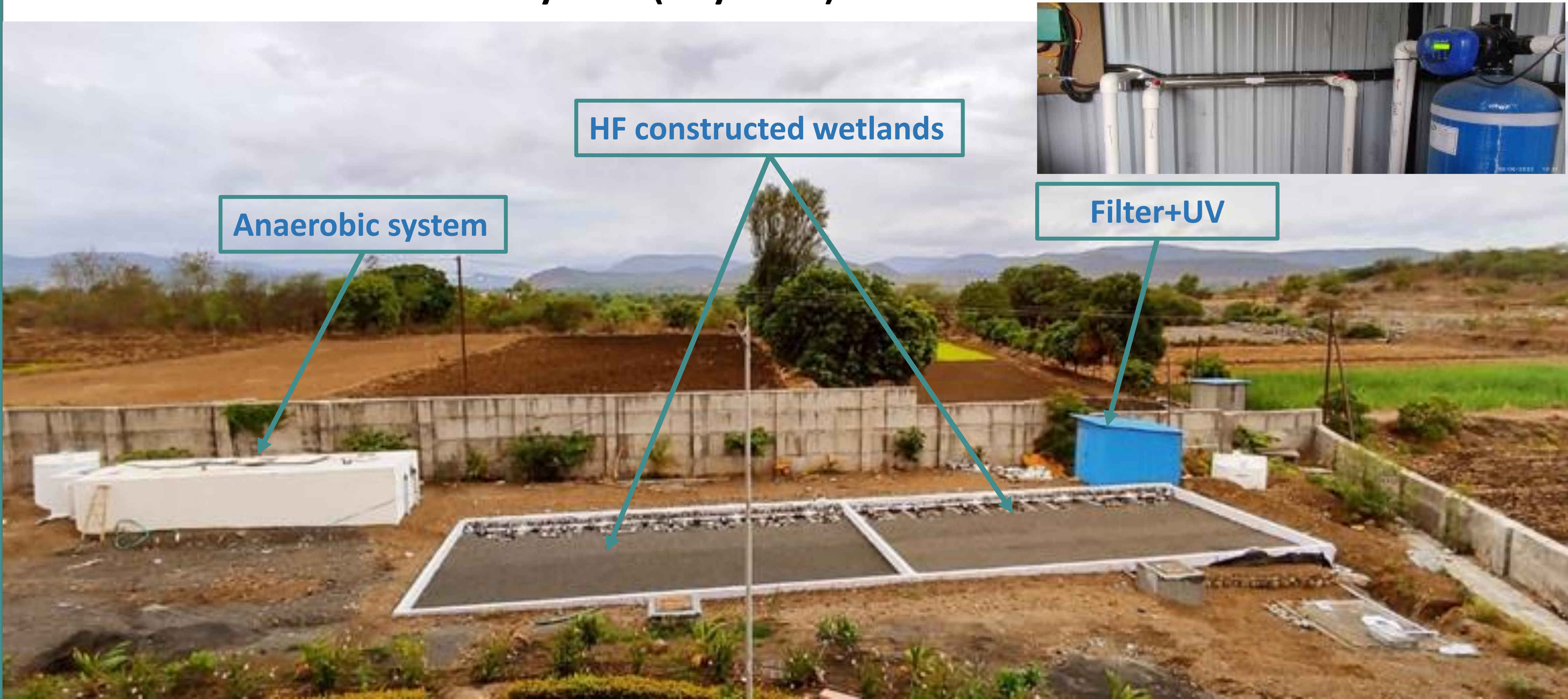
Wastewater Treatment System (July 2022)



Materials & Method

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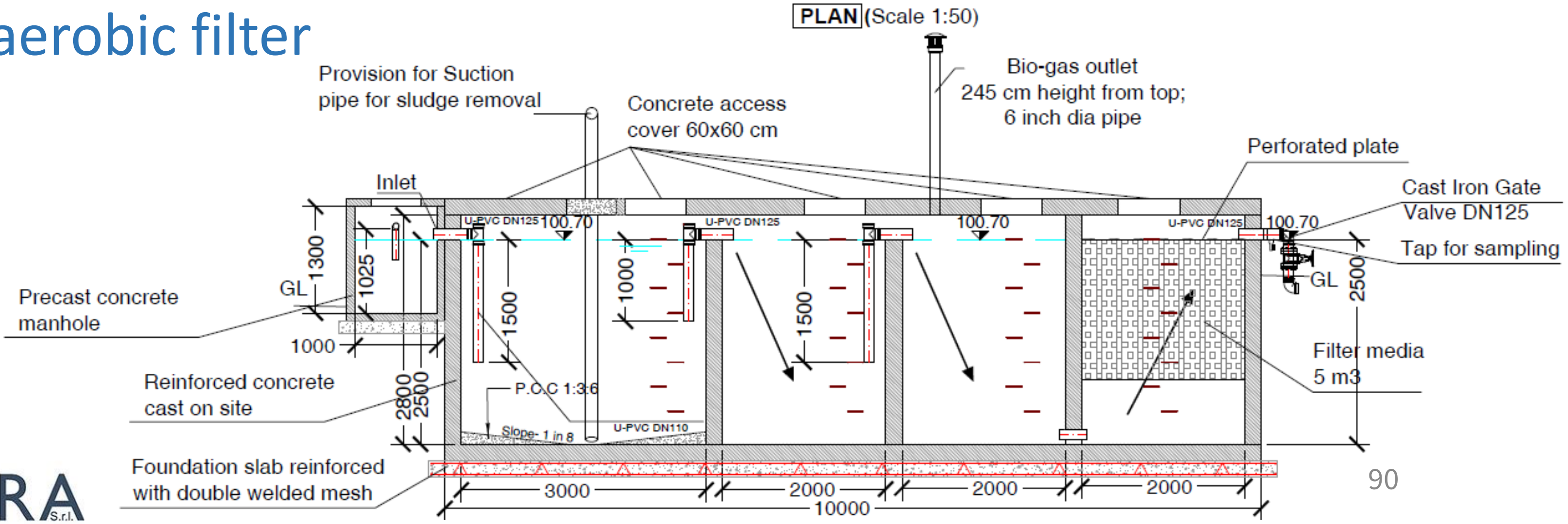
Anaerobic system

Units	Dimensions (m)	Volume (cum)	HRT max (d)	HRT min (d)
Settling Chamber 1 unit	3x2.5 (2.5 w.l.)	19	0,4	0,2
Anaerobic Baffled Reactor 2 chambers	2x2.5 each chamber (2.45 w.l.)	24,5	0,5	0,3
Up Flow Anaerobic Filter 1 unit	2x2.5 (2.4 w.l.)	12	0,2	0,2
Total	**13x2.5**	**55**	**1,1**	**0,7**

3 chambers + upflow anaerobic filter

Total HRT 0.7-1.1 days

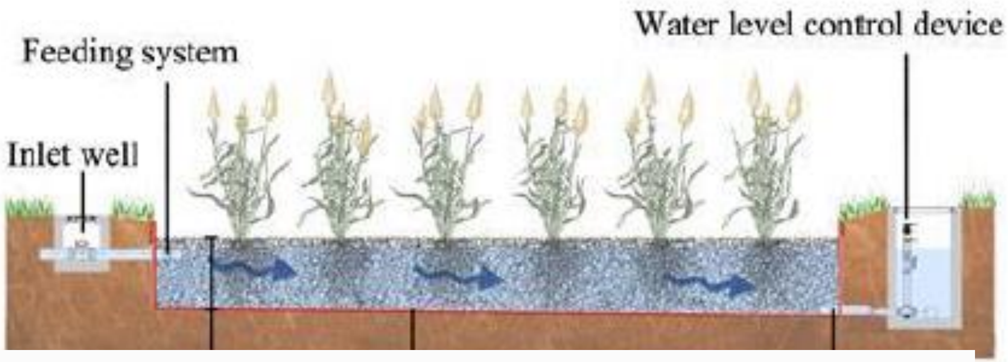


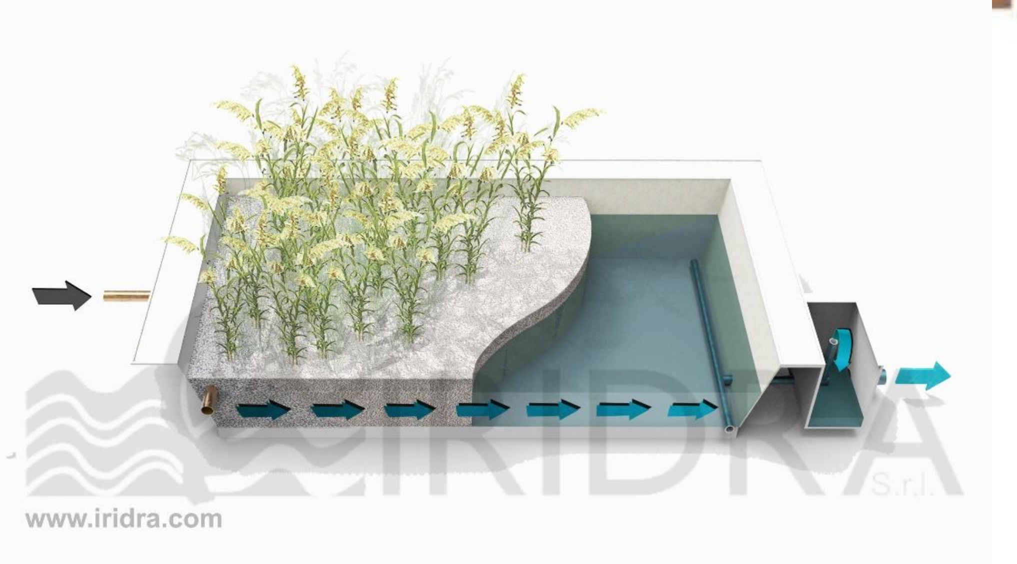
Materials & Method

Construted Wetland

CW: Horizontal flow type, fully saturated

>>> mainly anaerobic processes





Parameters	Dimensions	
HRT	0.75-1.2	days
Water level	0.7	m
Depth of filter media from bottom ● Crushed Gravel (20 mm) for the first half of the bed ● Crushed Gravel (10 mm) for the second half of the bed	0.8	m
Bed Size (n°2 beds in parallel)	14.5x8.5 = 123 each	m2
Type of plants	Canna Indica & Typha	

Low HRT → **More nutrients available for irrigation**

Materials & Method

Treated water Reuse

Fertigation of a **1450 m²** plot of **Guava trees** (plus Banana and Mango)

- Irrigation levels: **120%**, **100%** and **80%** of the evapotranspiration rate
- 48 Guava plants planted with a spacing of 6m x 6m
- Two replicates, 24 plants per replicate
- Each replicate consists of three rows with different irrigation levels, each row has 8 plants

- Guava: L-24 Indoori Pink variety
- Drip irrigation system
- 50-60 mL/min per drip emitter
- 2 drip emitters per plant

Banana Guava Mango

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Monitoring

Water quality monitoring
Physical-chemical and microbial parameters

Soil properties
Before irrigation and after harvesting

Guava growth monitoring
Twice x month

- Plant height
- Leaf area

Monitoring Results

Water quality monitoring – Q=50 m^3/day

July 2022 - Initial test after start-up (2 samplings) – high removal since the beginning

Parameters		Inlet	Outlet	IS 2296:1992 for Land of Irrigation (MOEFCC 2017 discharge st)	Removal (%)
pH		7.7	7.6	5.5 - 9	
TSS	mg/L	58	6 - 15	< 200 (100)	74 – 90
COD	mg/L	218	25 - 35		84 – 89
BOD3 (27°)	mg/L	87	8 - 15	< 100 (30)	83 – 91
Turbidity	NTU	54	3		
DO		0.5	5.6		
Chloride	mg/L	12	10 - 15		
Nitrate (as N)	mg/L	1.6 - 5.8	< 1		
Phosphate	mg/L	0.18 - 0.42	< 1		

Outlet of CWs

Monitoring Results

On going water quality monitoring Q=50 m ^{3} /day

16 – 30 September 2022 / 2 samplings (average values)

Parameters		Inlet	Ansys Out	CW Out	UV+DMF Out	IS 2296:1992 For land of irrigation (MOEFCC 2017 discharge st)	Total system Removal (%)
pH		7.1	7.5	7.7	7.7	5.5 – 9	
conductivity	dS/m	0.87	0.79	0.72	0.6		
Turbidity	mg/L	6.8	2.3	0.1	0.1		
TSS	mg/L	225.5	89	24	14.0	< 200 (100)	94
COD	mg/L	293	100	45	37.0		87
BOD3 (27°)	mg/L	102	41	16	16.0	< 100 (30)	84
TKN	mg/L	36.9	27.7	21.5	16.1		56
Nitrite (N-NO2)	mg/L	0.17	0.15	0.08	0.1		
Nitrate (N-NO3)	mg/L	2.4	1.6	1.6	1.4		94
Phosphate	mg/L	15.3	10.8	5.5	5.3		65
E-Coli	MPN/100 ml	> 4600	> 4600	> 4600	nil		
Micro nutrient-Zinc	mg/L	4.7	4.4	1.2	1.2		
Heavy Metals-Ar	mg/L	nil	nil	nil	nil		
Heavy Metals-Hg	mg/L	nil	nil	nil	nil		
Heavy Metals-Cd	mg/L	nil	nil	nil	nil		
Heavy Metals-Pb	mg/L	nil	nil	nil	nil		
colour		colour	colour	colourless	colourless		
odour		odour	odour	odour	odour less		

Monitoring Results

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Water quality monitoring

16 – 30 September 2022 / 2 samplings (Average values)

Removal (%)		
Parameters	**ANSYS**	**CW**
TSS	61	89
COD	66	85
BOD3	60	84
TKN	25	42
Nitrate	86	89
Phosphate	30	64

HF constructed wetland operative conditions

- HLR: 0.40 m/d
- OLR: 16.6 gBOD/m^2/d

Table 3.1 Main design parameters of HF wetlands for select countries.

	Czech Republic	Spain	US	UK
Treatment Step	Secondary	Secondary	Secondary	Tertiary
Pre-treatment	Screens + Imhoff tank	Screens + septic tank	Septic tank	Primary settling + biological treatment
Specific surface area requirement (m²/PE)	5	10	5 – 10	0.7
Maximum areal organic loading rate (g BOD_5/m²·d)	–	6	4 – 8	2 – 13

Dotro, G., Langergraber, G., Molle, P., Nivala, J., Puigagut, J., Stein, O., & Von Sperling, M. (2017). *Treatment wetlands* (p. 172). IWA publishing.

Design criteria

- Fine gravel (5–15 mm)

Secondary treatment

- HLR: up to 0.02–0.05 m³/m²/day
- OLR: up to 20 g COD/m²/day
- TSS load: up to 10 g TSS/m²/day

Tertiary treatment

- HLR: up to 0.4 m³/m²/day

Cross, K., Tondera, K., Rizzo, A., Andrews, L., Pucher, B., Istenič, D., ... & Mcdonald, R. (2021). *Nature-based Solutions for Wastewater Treatment*. IWA Publishing.

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Monitoring Results

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Soil properties

Geochemical and mineral content in the soil was analysed before irrigation and will be analysed after harvesting to understand the impact of the reuse of treated wastewater for irrigation.

Collected data before irrigation

Parameters		Result	Standards given by Ministry of Agriculture 2011
pH	---	7.81	< 8.5
Electric Conductivity	mS/cm	0.6	0.15 – 0.65
Calcium as Ca	mg/kg	197.8	< 200.00
Exchangeable Magnesium as Mg	mg/kg	55.4	< 55.00
Sodium Adsorption Ratio (SAR)	---	17.7	10-18
Total Nitrogen Content	%	0.089	Not Specified
Total Potassium as K++	%	0.028	Not Specified
Avail Potassium as K++	mg/kg	280	108-280
Available Phosphorus as P	kg/ha	13.71	10- 24.60
Total Iron as Fe	mg/kg	52830	Not Specified
Total Nickel as Ni	mg/kg	15.2	Not Specified
Total Zinc as Zn	mg/kg	33.6	Not Specified
Total Copper as Cu	mg/kg	105.8	Not Specified
Total Manganese as Mn	mg/kg	532.9	Not Specified
Total Mercury as Hg	mg/kg	BDL < 0.10	Not Specified
Total Cadmium as Cd	mg/kg	BDL < 0.10	Not Specified

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Monitoring Results

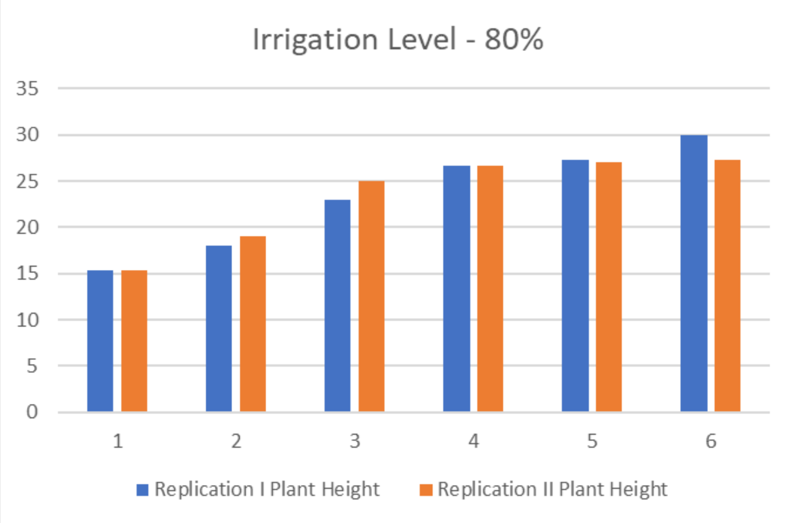
Guava growth monitoring

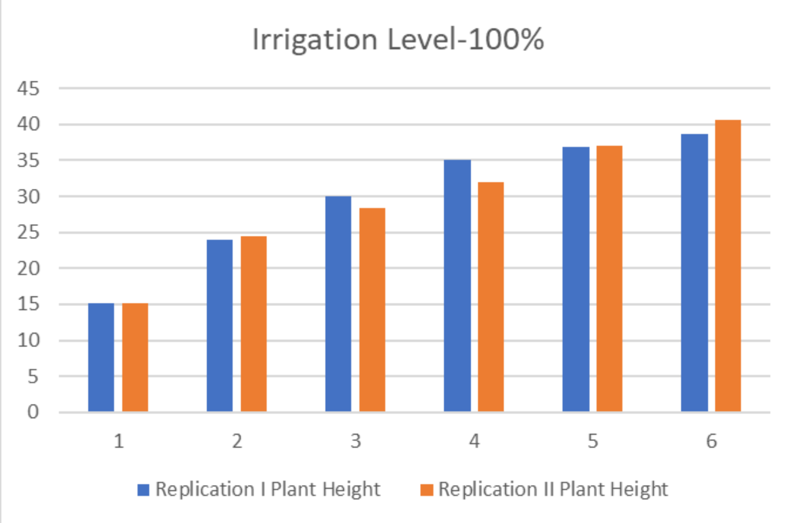
Monitoring Results

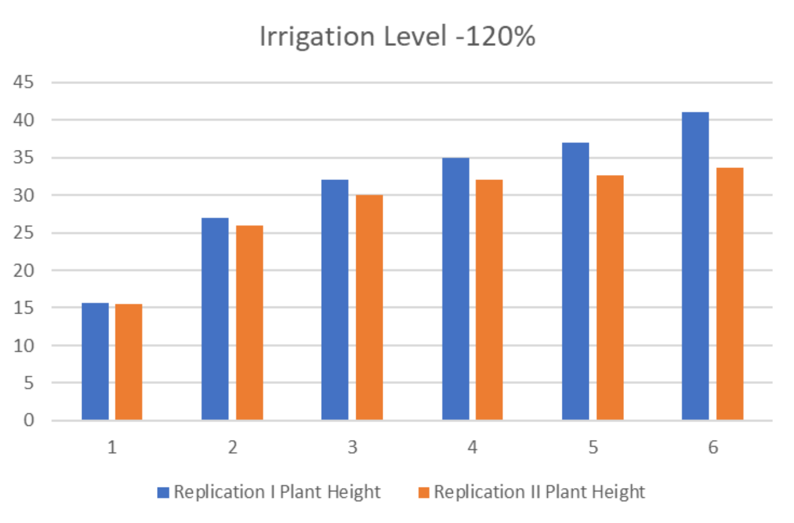
PAVITR

Guava growth monitoring

Plant height: graphs for fortnight height growth of guava (in cm)







increasing **growth rate** with an irrigation level of 100% compared to 80%, with little difference between 100% and 120%.

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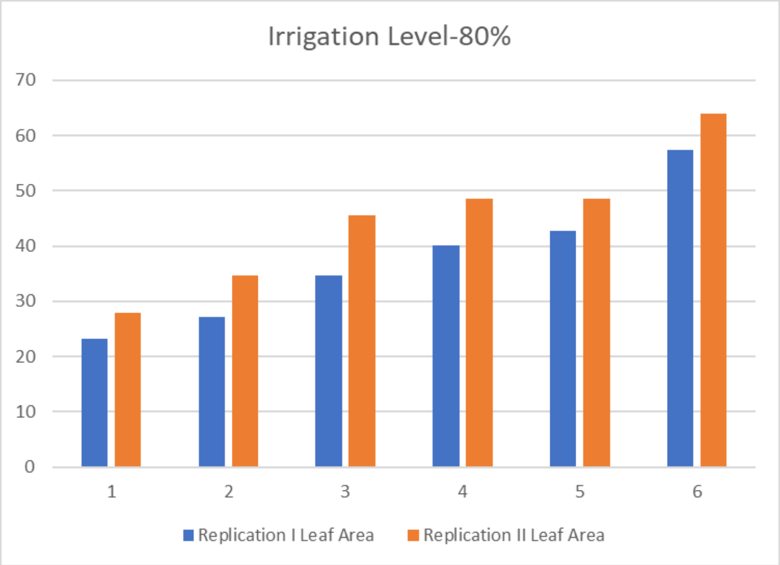
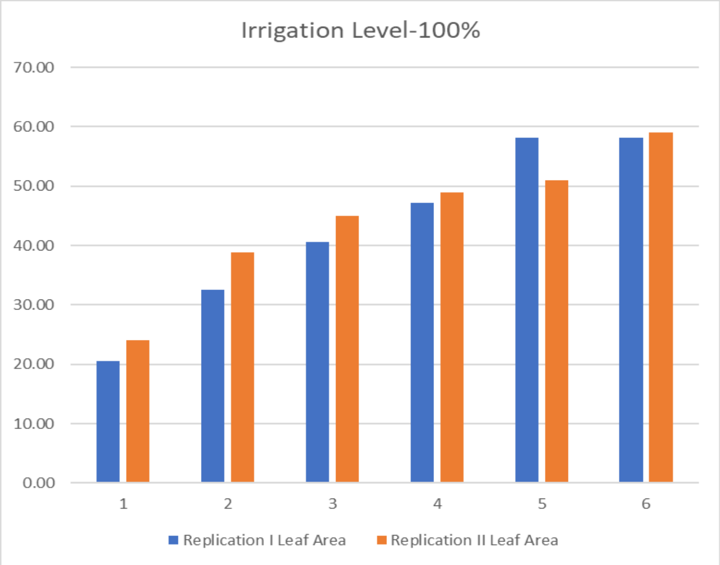
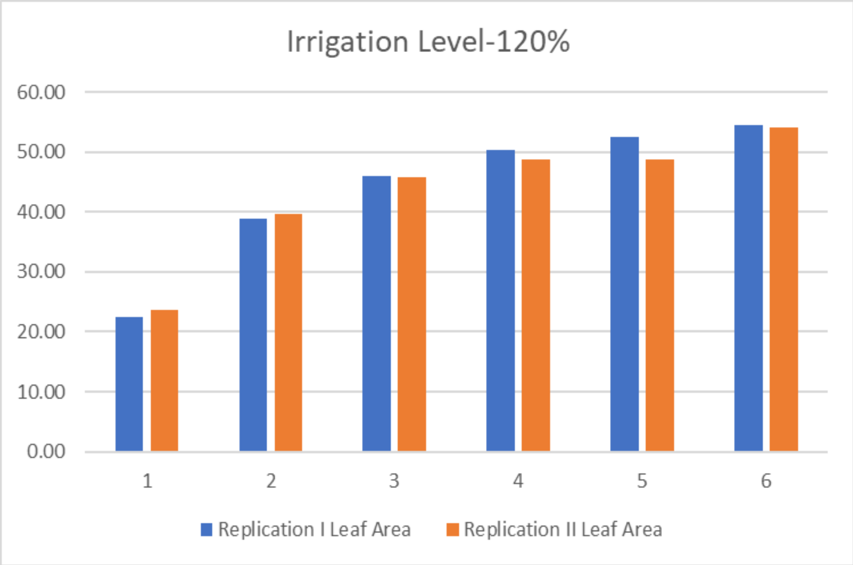
Monitoring Results

Guava growth monitoring

Leaf area: graphs for fortnight leaf area growth of guava (in cm^2)







Key messages

- The values of treated wastewater met water **quality standards** for land irrigation (according to IS 2296:1992) and discharge (MOEFCC 2017), as well as Class A of Eu directive for water reuse.

- Despite low HRT, N removal is significant due also to limited ammonia content in the influent. Horizontal flow (HF) achieves almost complete denitrification. If the objective is to leave more nutrients in the effluent, unsaturated Vertical flow systems (VF), mainly aerobic and transforming ammonia in nitrate, could be more effective

- The graphs show the best effectiveness on growing rates with an irrigation level of 100% ET. Future monitoring will provide interesting insights on the optimization of **fertigation** with treated wastewater, focusing on the yield of the crops and nutrient content.

- Further **monitoring** is ongoing, including also an analysis of geochemical and mineral content in the soil to understand the impact of the reuse of treated wastewater for irrigation.

Homework

Introduction

PAVITR

Design a HF wetland for a single-family home (**5 PE**) in a temperate climate. **BOD5** effluent target is **30 mg/L**.

Assumptions:

- A septic tank for pre-treatment, and that the septic tank removes 1/3 of the BOD5 load.
- An average per capita wastewater generation of 150 L/d and a per capita BOD5 load of 60 g per person and day (DWA, 2017).
- HF bed length-to-width ratio between 2:1 and 4:1
- Filter medium porosity: 0.35

Dotro, G., Langergraber, G., Molle, P., Nivala, J., Puigagut, J., Stein, O., & Von Sperling, M. (2017). Treatment wetlands (p. 172). IWA publishing.

Introduction

PAVITR

P-k-C* parameters

Pollutant	HF k_A-rate (m/yr)
BOD_5	25
TN	8.4
NH_4-N	11.4
NO_x-N	41.8
Thermotolerant coliform	103

Example areal-based reaction rate coefficients (50th percentile)

Parameter	HF	VF	FWS
BOD_5	3	2	1
TN	6	n.g. [a]	3
NH_4-N	6	6	3

[a] n.g. = not given

Examples of P values for HF, VF, and FWS wetlands

Parameter	HF	VF	FWS Lightly Loaded	FWS Heavily Loaded
BOD_5	10	2	2	10
TN	1	0	1.5	
NH_4-N	0	0	0.1	0.1

Example background concentrations *(C*)* in mg/L

Dotro, G., Langergraber, G., Molle, P., Nivala, J., Puigagut, J., Stein, O., & Von Sperling, M. (2017). Treatment wetlands (p. 172). IWA publishing.

Your homework is

1. Calculate the inflow, organic load and influent concentration.

2. Calculate the HF bed area based on the treatment target.

Solution

1. Calculate the inflow, organic load and influent concentration

- Inflow: 0.75 m3/d
- Organic load: 200 gBOD/d
- Influent concentration: 266 mgBOD/L

2. Calculate the HF bed area based on the treatment target

- Area: 44 m2 (P-k-C* approach)
- Width: 4 m; length: 11 m; depth: 0.5 m
- Cross-sectional OLR: 100 gBOD/m2/d

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