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

French Reed Bed Constructed Wetland

Prepared by:
Riccardo Bresciani
IRIDRA Srl

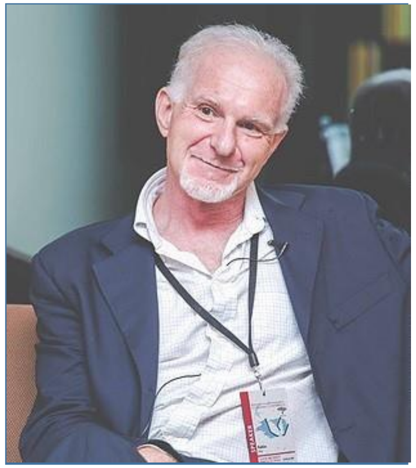
IRIDRA S.r.l.

PAVITR

Copyright and Disclaimer

Copy it, adapt it, use it – but acknowledge the source!

Introduction to the authors



Name and Last Name

Technical director Iridra

Environmental Chemistry

Expert in nature based solutions processes and sustainable water management

Email masi@iridra.com

Name and Last Name

Project manager Iridra

Environmental Engineer

Expert in design, supervision and training on Constructed Wetland wastewater treatment plants

Email bresciani@iridra.com

Name of the organization

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.

www.iridra.com

Learning objectives

PAVITR

At the end of this session, participants will:

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

Agenda of the session

PAVITR

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

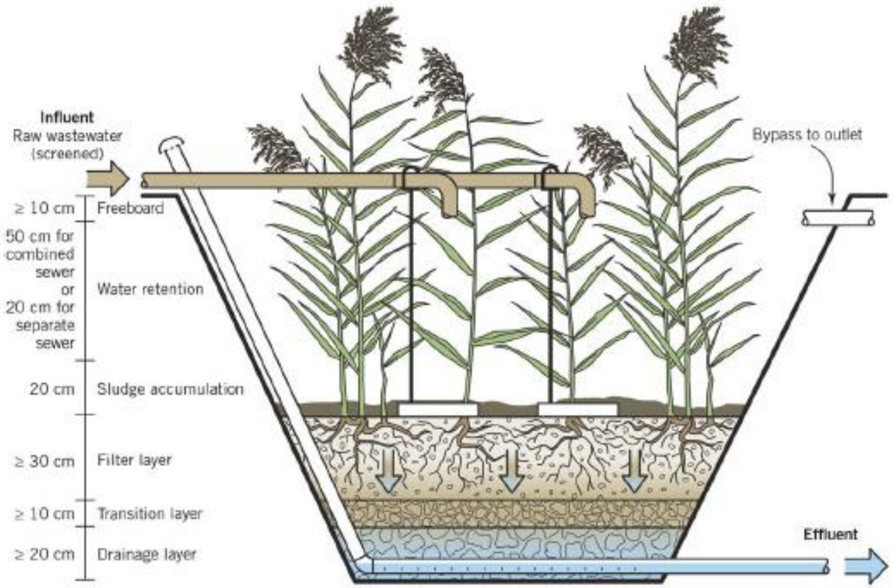
French Reed Bed (**FRB**)

Constructed Wetland

French Reed Bed (FRB)

Description

French Reed Beds (FRBs) are a particular type of Vertical Flow constructed wetlands designed and operated in order to treat **raw sewage**. The bed is filled with different layers of fine and coarse gravel. Depending by the required limits at the outlet, it can be stand alone or followed by a second stage (generally a VF bed with sand and gravel, but it can be constituted also by any other type of treatment wetland).



Profile of French VF cells; first stage

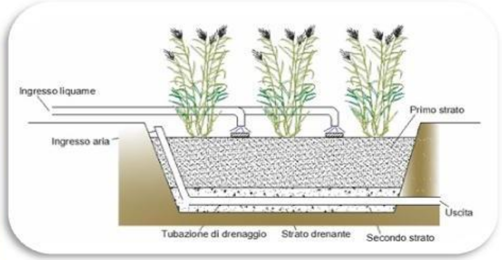
DOTRO et al. 2017

French Reed Bed (FRB)

Description

Receiving raw wastewater, an organic layer is formed on top of the bed that must be removed after 10-15 years. Thus, the main advantage of FRBs is that there is **no need for any primary treatment**, further reducing the Operation and Management (O&M) costs of nature-based solutions for wastewater treatment. Moreover, removal efficiencies are high with a relatively low areal footprint for nature-based systems, making these systems particularly suitable for small communities (RIZZO et al. 2018).



French Reed Bed (FRB)

PAVITR

General overview

Two-stage system:

- 1st stage - highly permeable VF beds
- 2nd stage - VF or HF beds

Raw wastewater fed directly into the 1° stage:

- Absence of general pretreatment (e.g. Imhoff tank)
- Sludge layer production

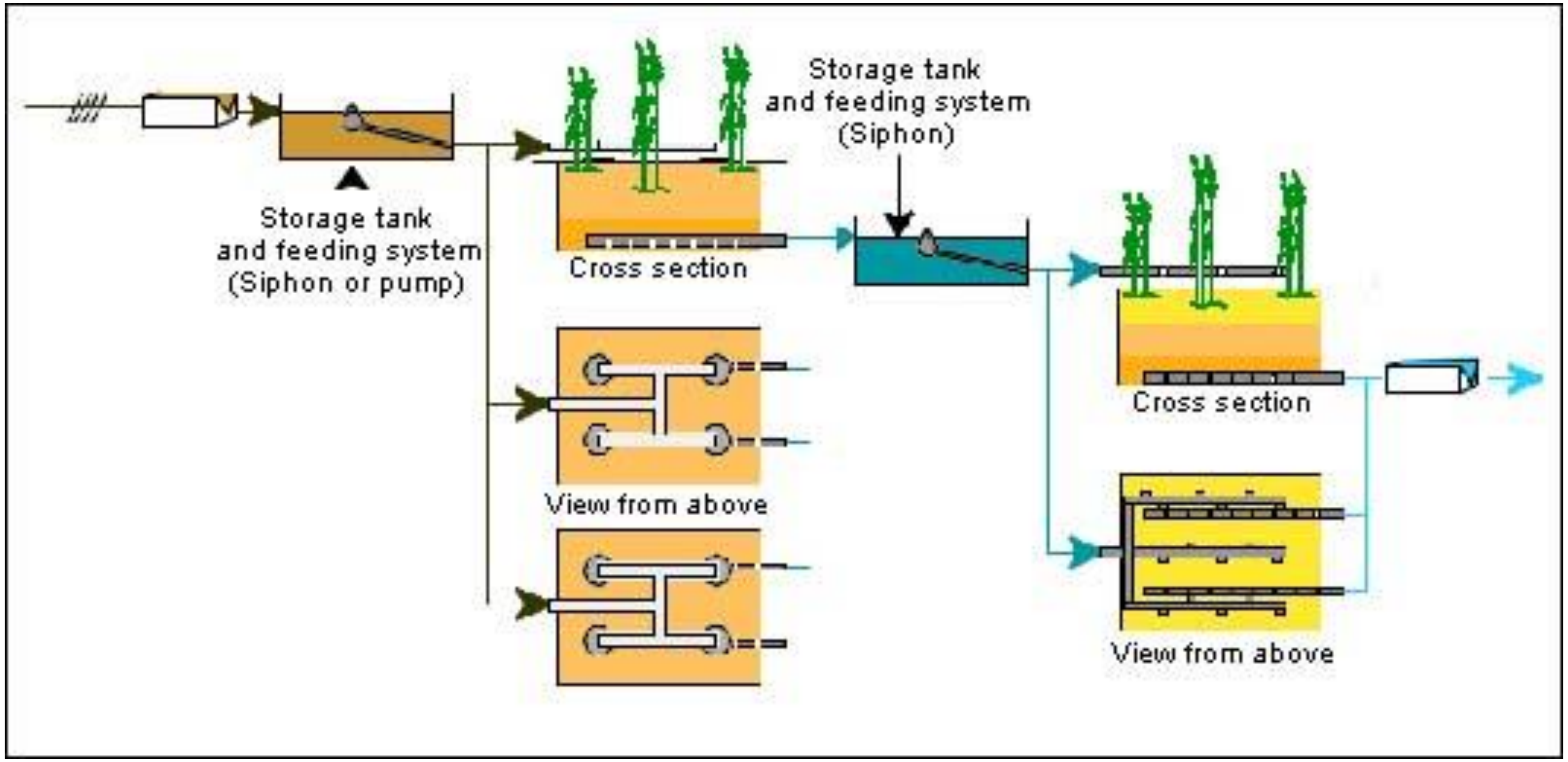
Advantages

- Minimum footprint (1-2 m^2/person)
- Sludge reuse (compost)

IRIDRA S.r.l.

French Reed Bed (FRB)

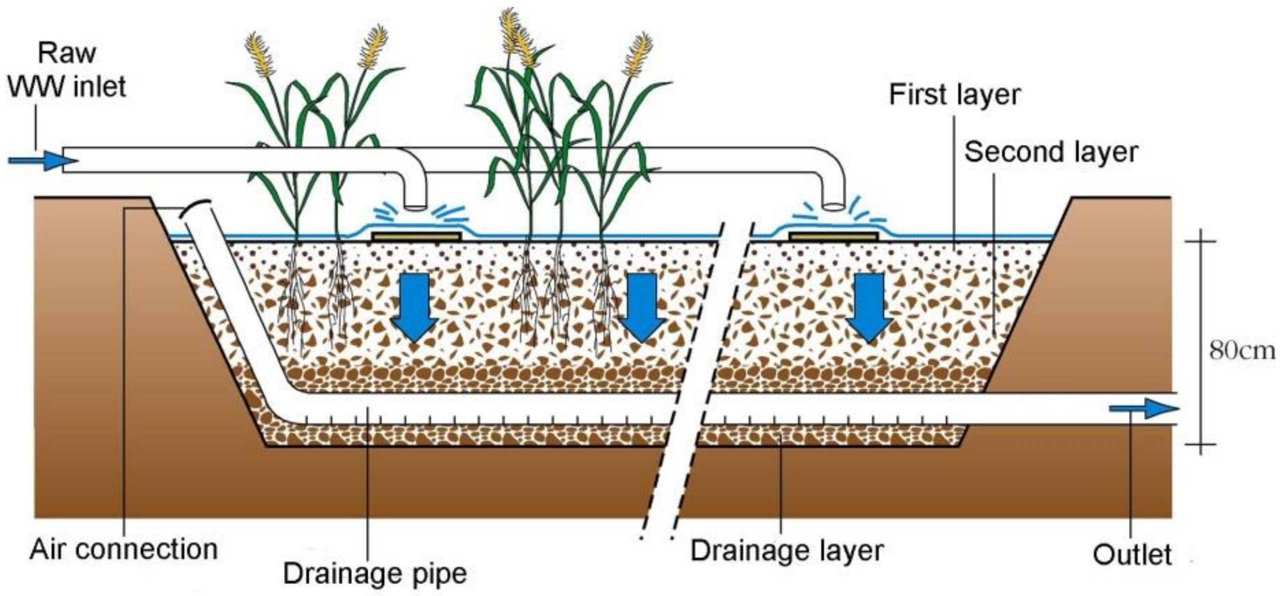
General scheme



French Reed Bed (FRB)

Functioning of 1st stage

- Vertical Flow
- Aeration pipe
- Design based on an acceptable organic load for dry weather flow



French Reed Bed (FRB)

Performance of 1st stage

- COD removal > 80%
- SS removal ≈ 90 %
- TKN removal 35 to 60% depending on the height of the filtration layer made with pea-gravel

		COD		SS		TKN	
520 < COD < 1400 (mean 840) mg.L^{-1}		% Removal	Outlet concentration mg.L^{-1}	% Removal	Outlet concentration mg.L^{-1}	% Removal	Outlet concentration mg.L^{-1}
	Mean **(N)**	82 ± 3 (34)	145 ± 24 (34)	89 ± 3 (34)	33± 7 (34)	60 ± 6 (34)	35 ± 7 (34)
	SD	7	70	7	19	16	18

French Reed Bed (FRB)

PAVITR

General performance of the two-stage system

- TKN removal 90%
- Almost complete nitrification (conc. KN below 10 mg.L-1)

mean Inlet COD = 840 $mg.l^{-1}$ (520- 1400) HL < 0.75 $m.d^{-1}$	COD		SS		TKN	
	Removal %	Outlet conc ($mg.l^{-1}$)	Removal %	Outlet conc ($mg.l^{-1}$)	Removal %	Outlet conc ($mg.l^{-1}$)
1^{st} stage	82	145	86	33	60	35
2^{nd}stage	60	55	72	11	78	6
Global	**92**	**60**	**96**	**15**	**90**	**8**

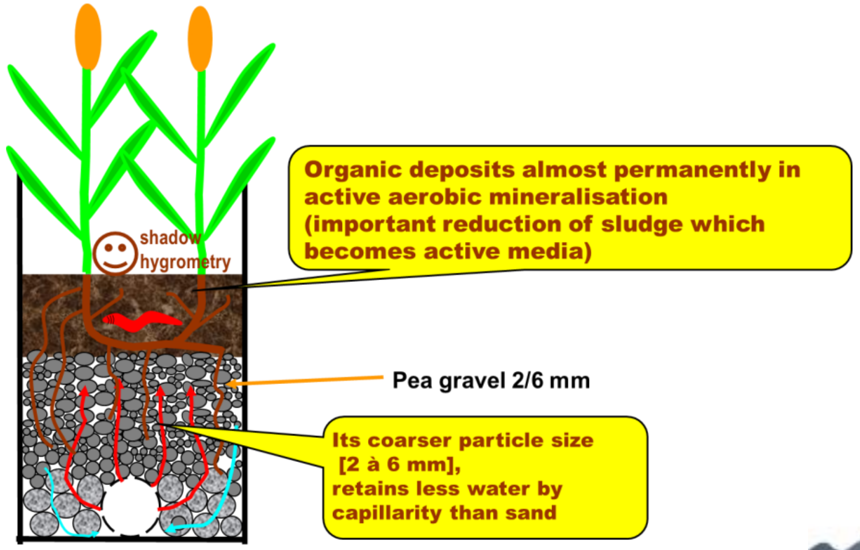
IRIDRA S.r.l.

French Reed Bed (FRB)

Reasons of 1st stage high performances

- A good distribution of the SS on the entire surface of the filter (specific flow of at least 0.5 m3/h/m2)
- Achievable by gravity with favourable topography
- **Sludge layer** at the end of the feeding period
- The **sludge layer** is a biologically active layer

It remains about 5 mm of SS on the filter surface



IRIDRA S.r.l.

French Reed Bed (FRB)

Sludge layer

- 1.5 cm/year accumulation due to 60 % of mineralisation
- High organic matter content
- Removal of sludge layer every 10-15 years without compromising FRB

French Reed Bed (FRB)

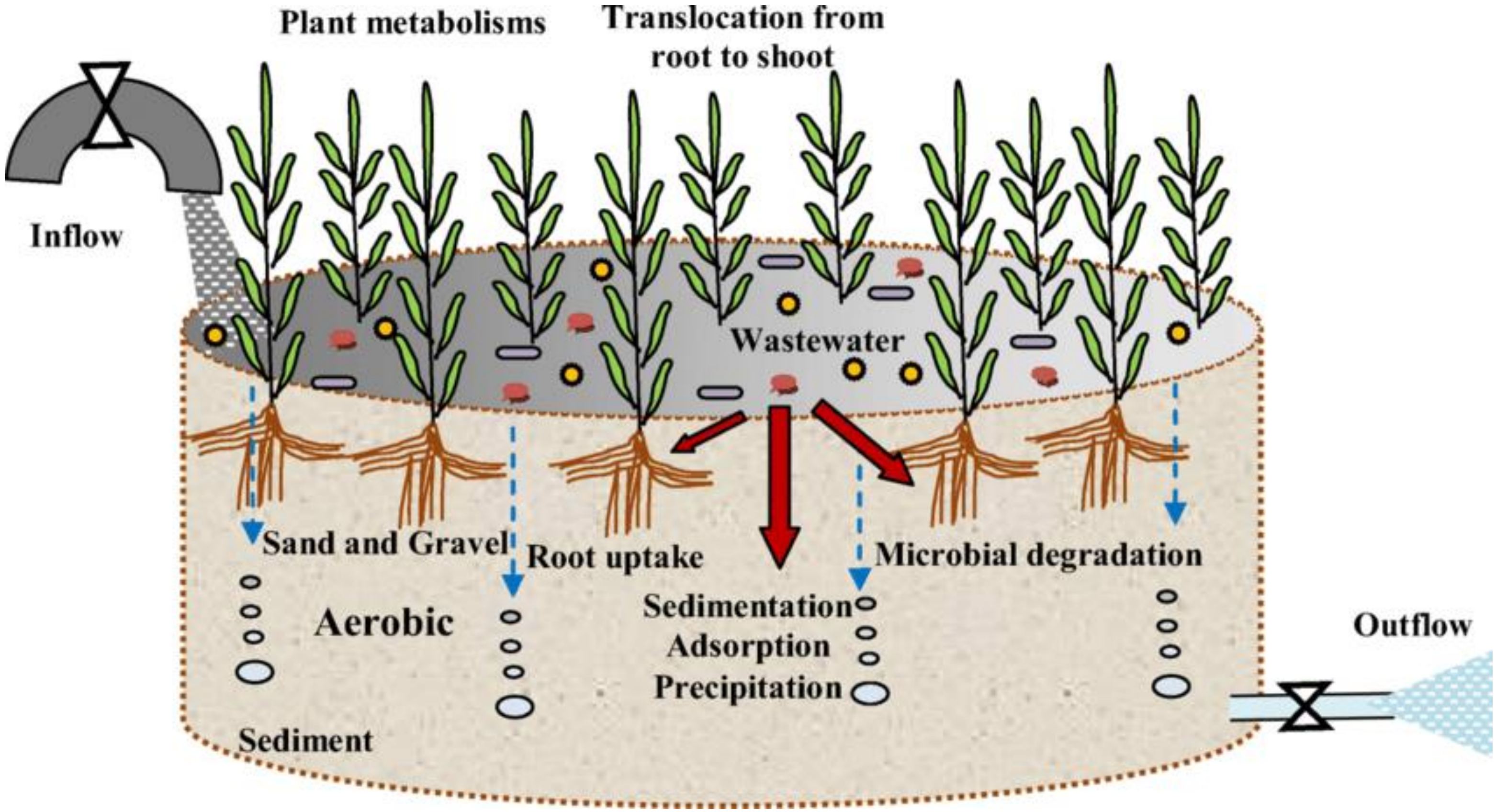
PAVITR

The raw wastewater is directly fed to the first stage of the FBR system, and filters through the filter layer, before passing over to the second stage. the organic top layer accumulates on the surface of the first stage with a rate of **2-3 cm per year**, and must be removed after **10-15 years**, when it is stabilized and can be used as a soil conditioner.

Double-stage systems guarantee a high level of organics, solids and ammonia removal, as well as a good bacteria reduction. In fact, already the first stage guarantees significant removal of organics, solids, as well as a good nitrification rate. A higher denitrification rate could be obtained with a saturation bottom layer.

IRIDRA S.r.l.

Removal mechanisms



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

Removal mechanisms

PAVITR

The systems treat screened domestic wastewater.

- First stage filters: effective for removal of organic matter and TSS

DOTRO et al. 2017

- Second stage filters: polishing effect for COD, BOD5 and TSS

	Hydraulic Load (m/d)	COD ($g/m^2 \cdot d$)	BOD_5 ($g/m^2 \cdot d$)	TSS ($g/m^2 \cdot d$)	TKN ($g/m^2 \cdot d$)
First stage	0.7	350	150	150	30
Second stage	0.7	70	20	30	15
Final effluent concentration	–	75 mg/L	15 mg/L	15 mg/L	15 mg/L

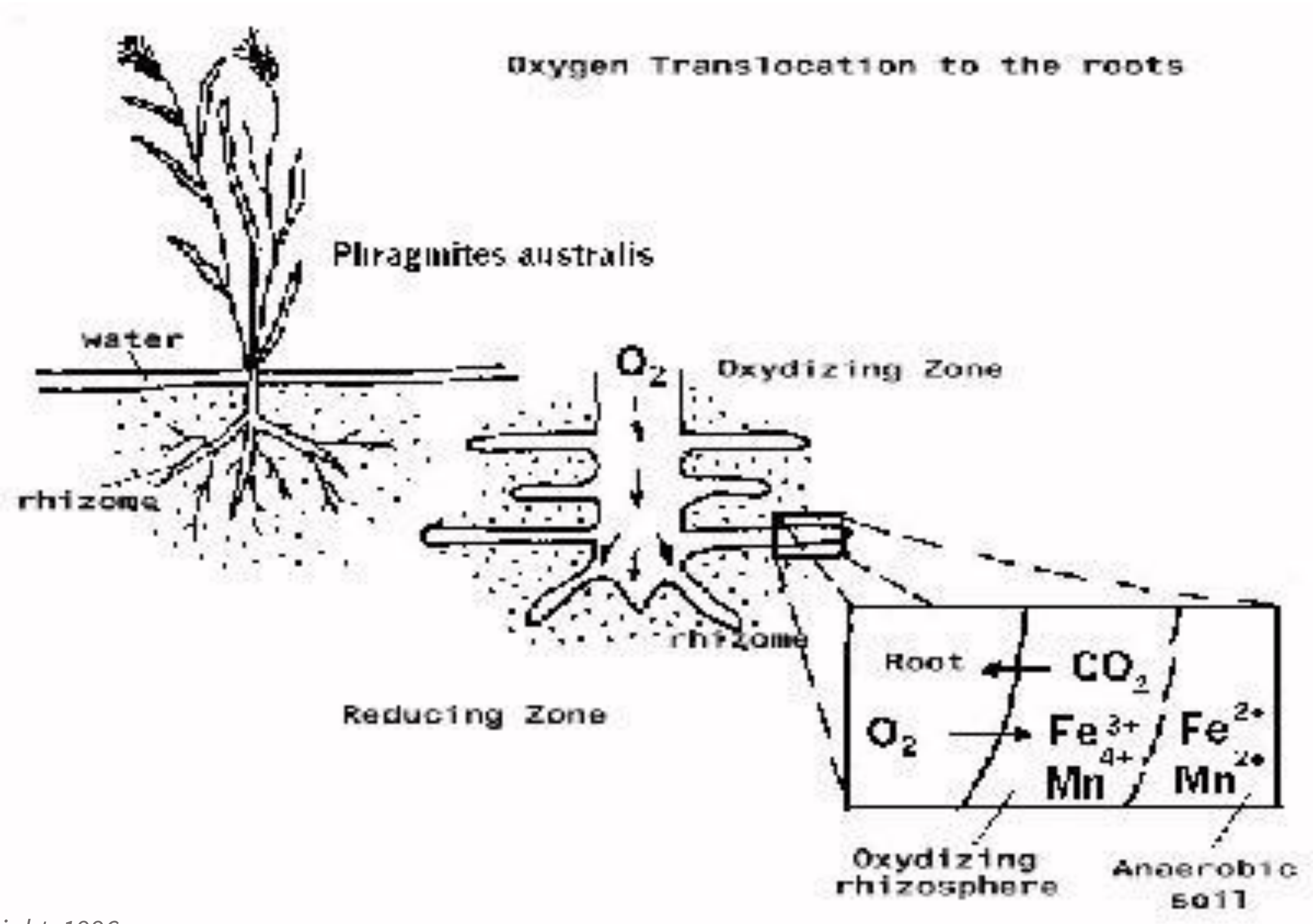
Langergraber, G., & Dotro, G. (2019).

IRIDRA S.r.l.

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 O_2 demand of wastewater).
- other functions not directly related to the treatment process

The role of plants



Source: Kadlec&Knight, 1996

Design of **the technology**

PAVITR

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.

FRB system for 1000 P.E. in Central Italy, operating since 2011

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 Outlet devices
- Cells configuration (series and/or parallel)
- Choice of macrophytes
- Treatment goals (in terms of specific pollutants overall removal)

General CW Design criteria

PAVITR

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

IRIDRA S.r.l.

General CW Design criteria

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

General CW Design criteria

PAVITR

Decisional tree: STEP 3

Preliminary sizing

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

IRIDRA S.r.l.

General CW Design criteria

PAVITR

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

IRIDRA

General CW Design criteria

PAVITR

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

IRIDRA S.r.l.

FRB Design

FRB Design

General overview

Two-stage system:

- 1st stage - highly permeable VF beds
- 2nd stage - VF or HF beds

Raw wastewater fed directly into the 1° stage:

- Absence of primary treatment (e.g. Imhoff tank)
- Only pre-treatment is necessary (manual or automatic coarse screening)
- Sludge layer production

Advantages

- Minimum footprint (1-2 m^2/person)
- Sludge reuse (compost)

FRB Design

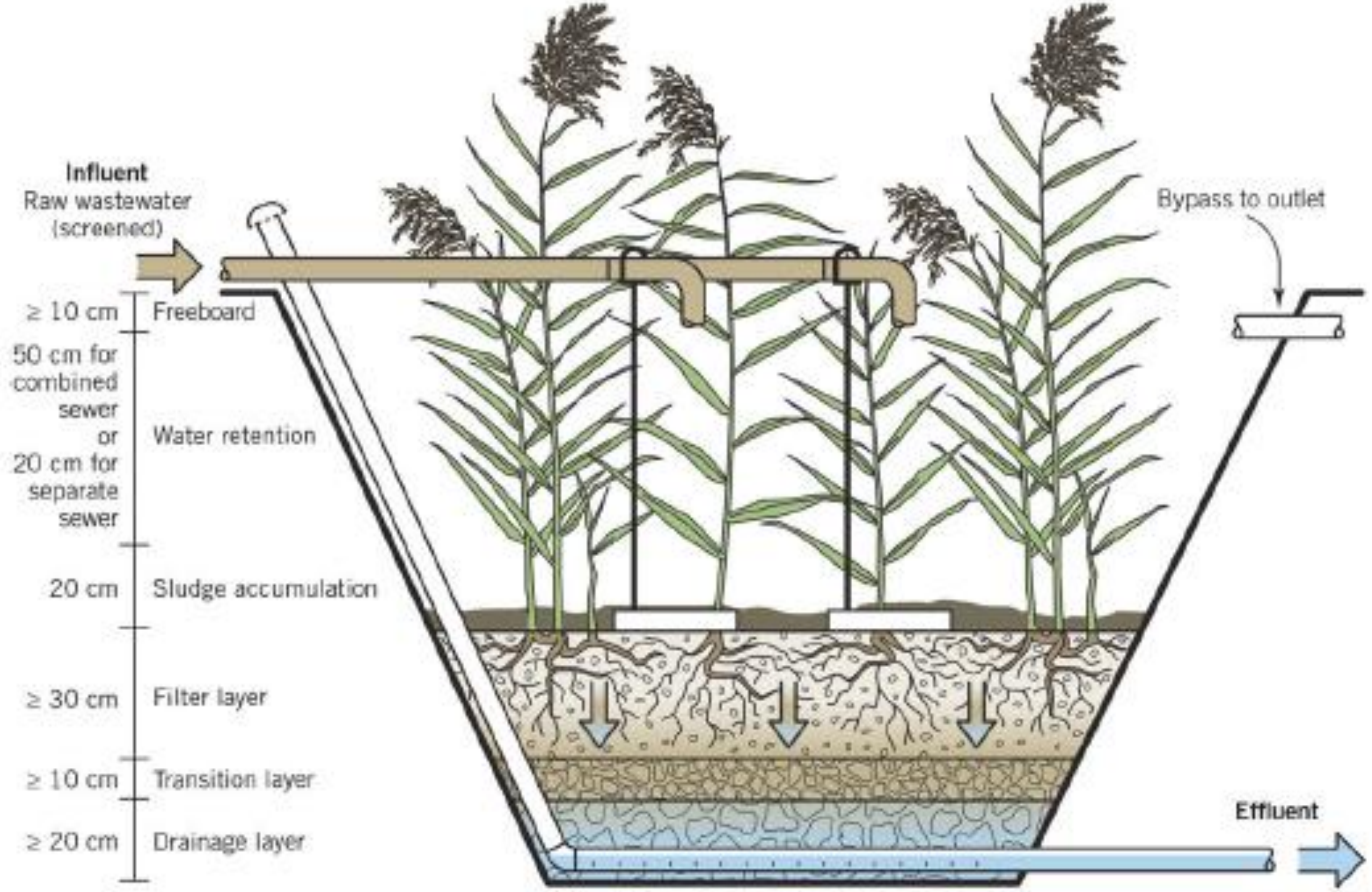
General overview

FRB are typically comprised of:

- Plastic liner
- Filter layer first stage:
    - 2-6 mm gravel (30-80 cm),
    - 5-15 mm gravel (10-20 cm),
    - 20-60 mm gravel (20-30 cm)
- Vegetation (generally Phragmites spp)
- Drainage system with slots with chimneys for aeration
- Distribution system, diameters larger than 110 mm are recommended.

FRB Design

General overview

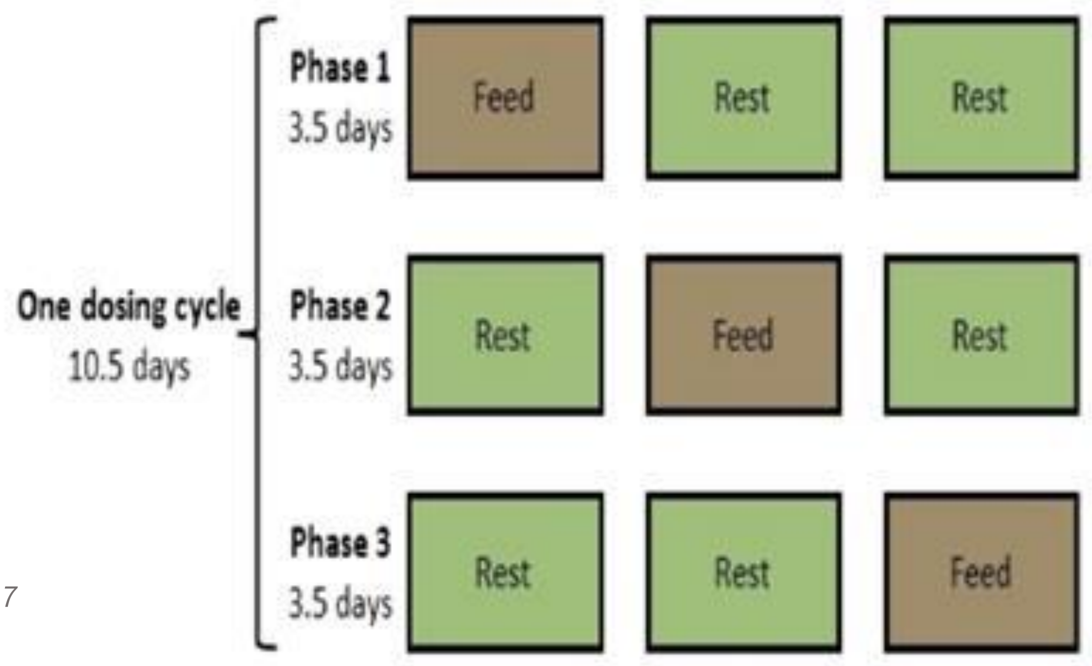


source: DOTRO et al. 2017

FRB Design

General overview

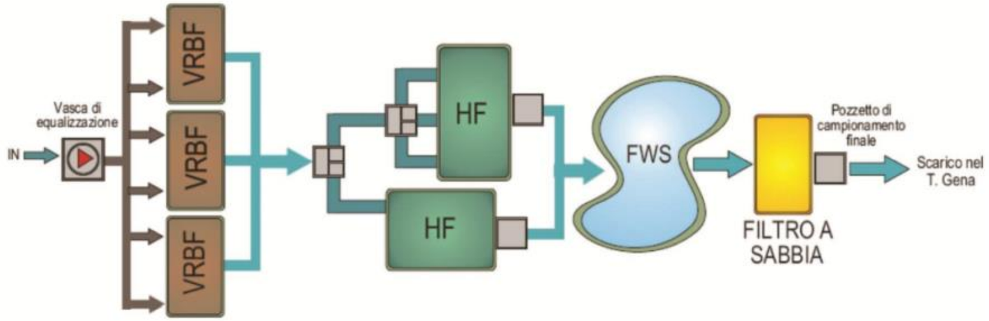
FRBs are generally divided into three (or multiples of three) cells (but also 2 or 4 cells can be designed), in such a way as to feed one bed at once and allow the other two to rest and maintain aerobic conditions. The feeding cycle lasts 3-4 days, during which the cell is fed in batches, with a break of 1-2 hours between one batch and the next one, followed by a resting period of 7 days

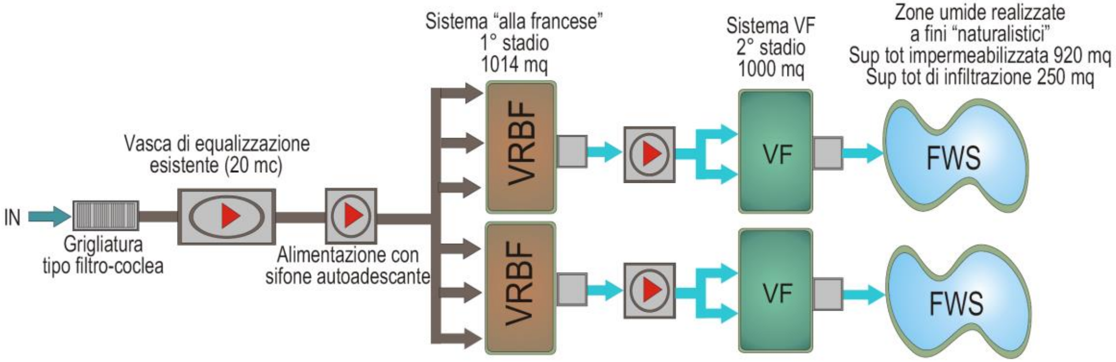


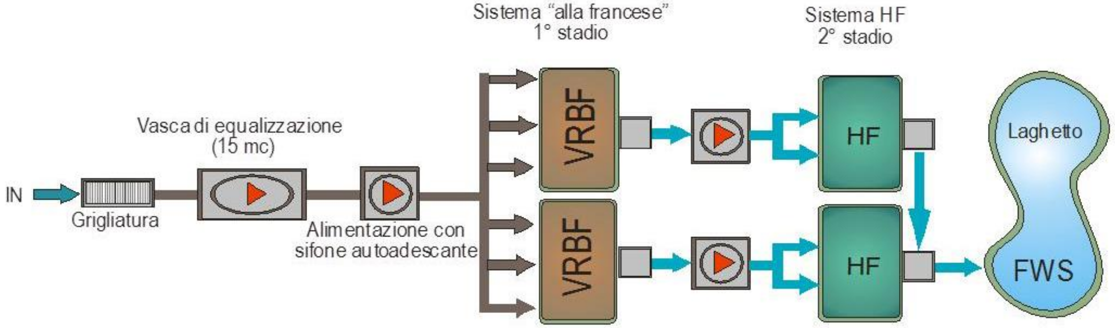
source: DOTRO et al. 2017

FRB Design

Different schemes



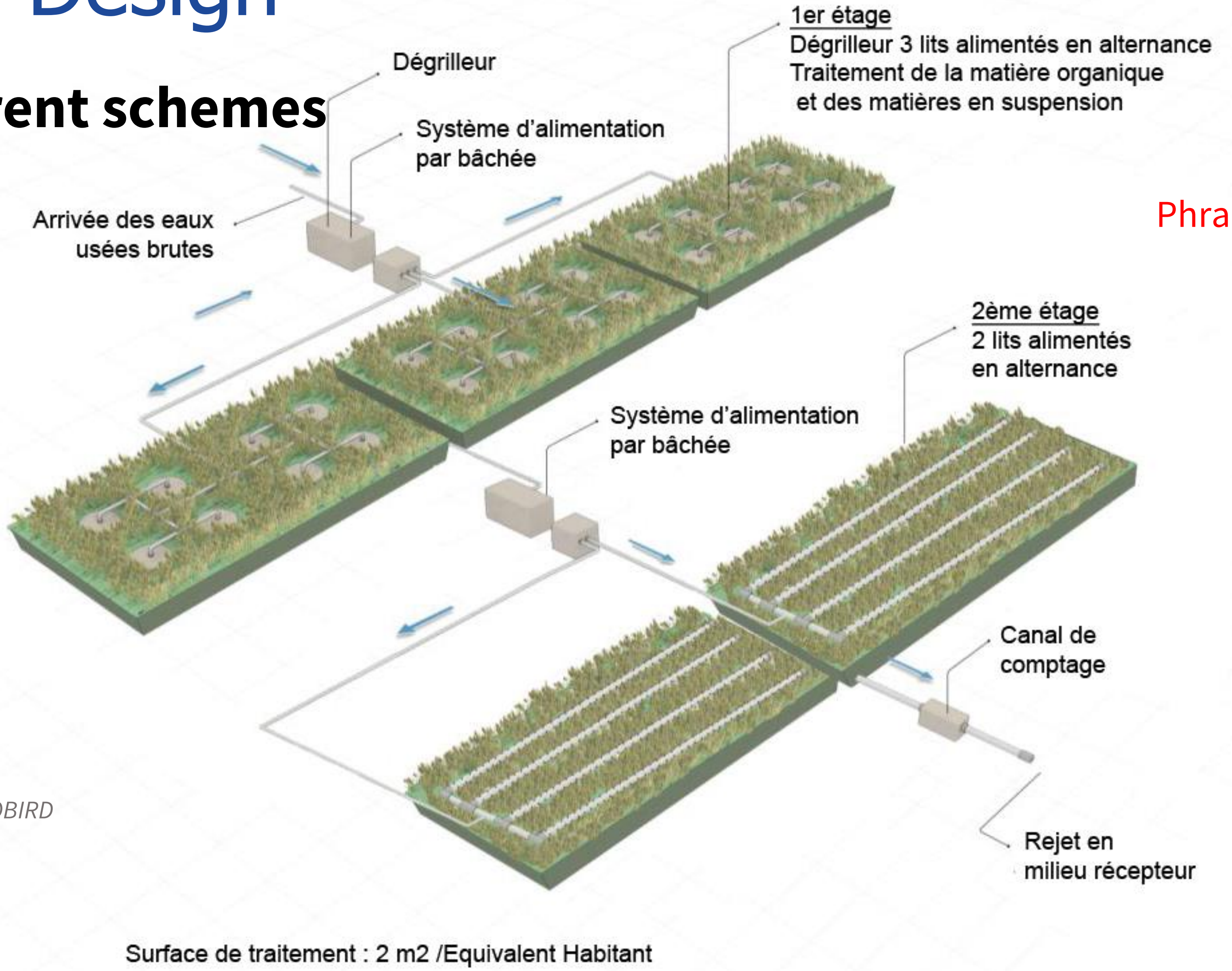




source: IRIDRA

FRB Design

Different schemes



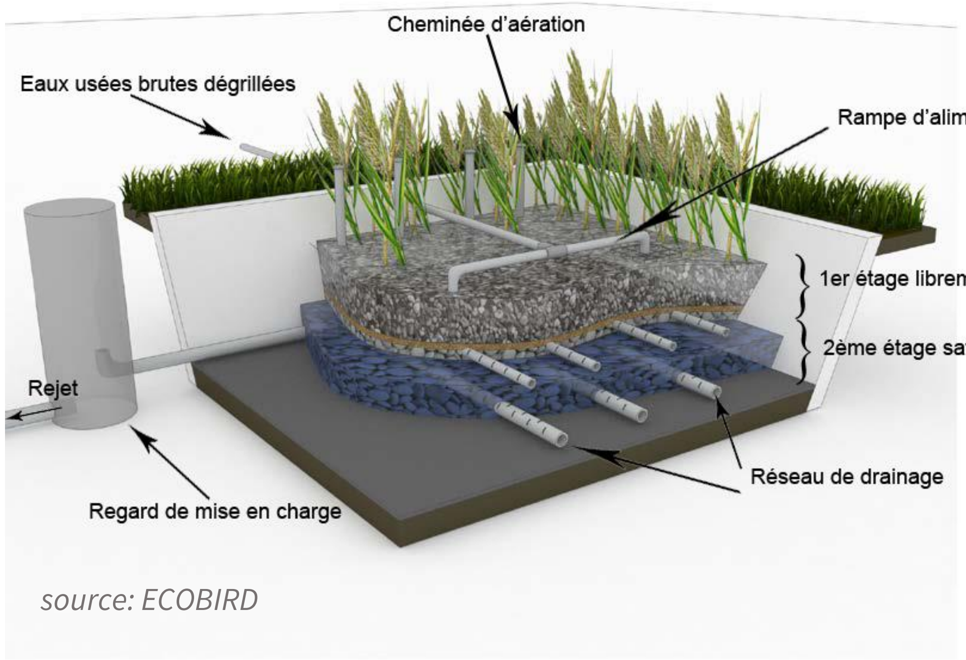
Phragmifiltre® (ECOBIRD)

source: ECOBIRD

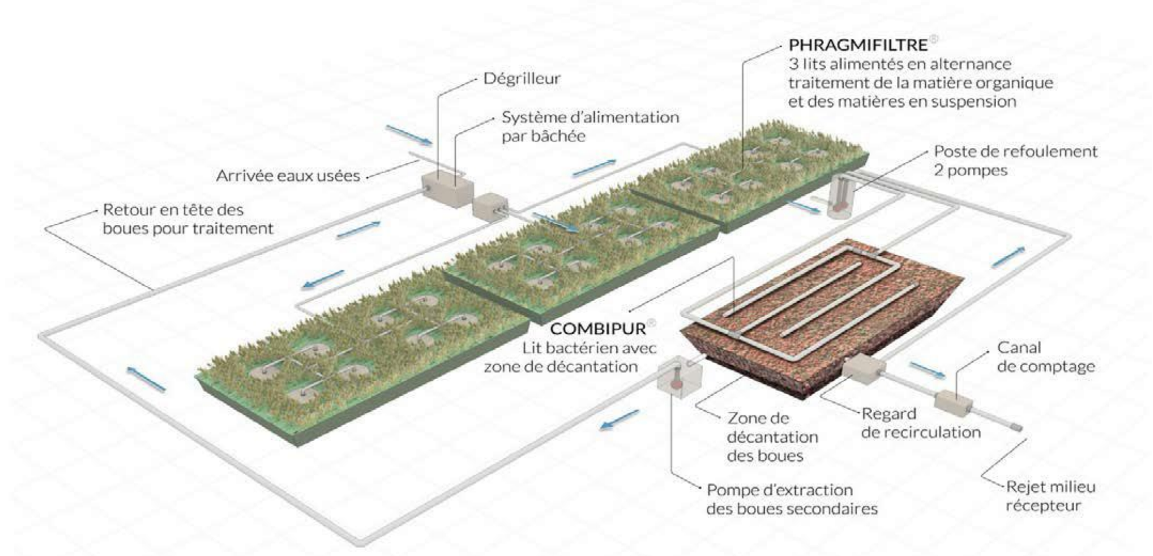
FRB Design

Different schemes

BiHo-filtre® (ECOBIRD)



source: ECOBIRD



Combipur® (ECOBIRD)

FRB Design

Design recommendations

1. Pretreatment
2. FRB
    - Sizing
    - Feeding
    - Vegetation
    - Other

source: IRIDRA, Val delle Rose Winery, Cecchi group, Tuscany, Italy

FRB Design

1. Pretreatment – screening

Recommendations

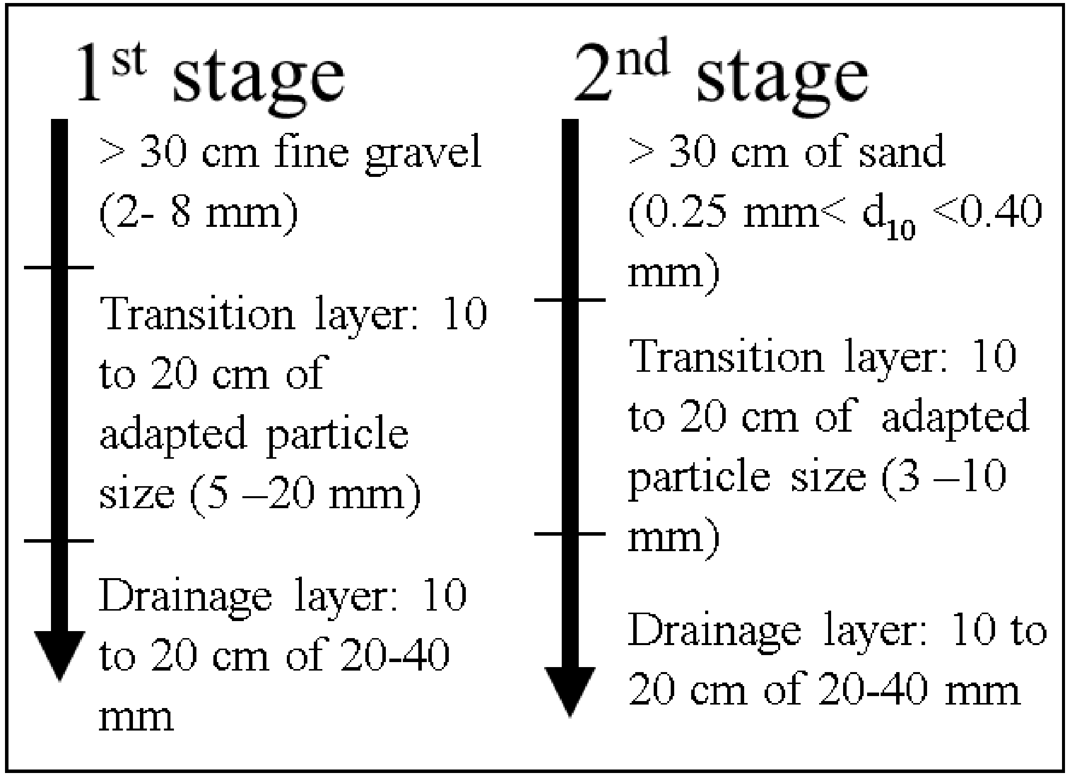
- The screening is mandatory, its function is the protection of the system, and also avoids obstruction to the flow.
- provide a bypass in case of clogging
- stainless steel grid (limiting the corrosion)

source: Aquasaf, manual screening for small plants

FRB Design

2. FRB - sizing

- 1st stage (FRB): 1.2 $m^2.PE^{-1}$
- 2nd stage (VF): 0.8-1.5 $m^2.PE^{-1}$
- Thickness of the layers and materials



FRB Design

2. FRB - feeding

- Maximum organic loads

  - based on an acceptable organic load for dry weather flow

Hydraulic load ($m.d^{-1}$)		COD load ($g.m^{-2}.d^{-1}$)		SS load ($g.m^{-2}.d^{-1}$)		TKN load ($g.m^{-2}.d^{-1}$)	
All	oper	All	oper	All	oper	All	oper
0.12	0.37	100	300	50	150	8-10	25-30

- Feeding/rest period

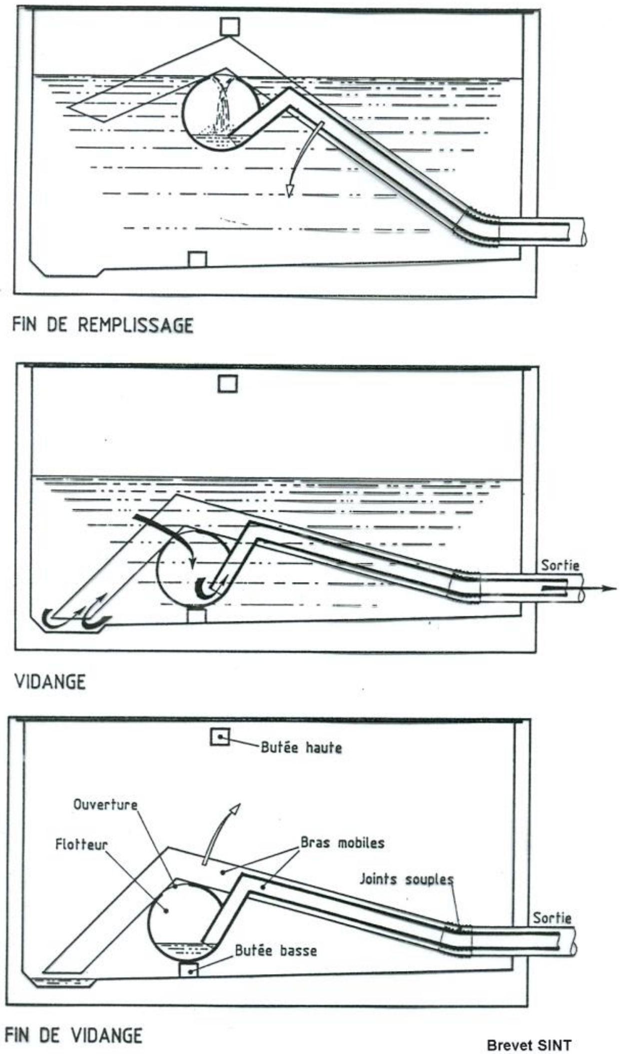
  - 3.5/7 days at the 1st stage and 3.5/3.5 days at the 2nd stage

FRB Design

2. FRB – feeding distribution

By gravity:
Special self priming Siphon → no energy
It requires MIN 1-1.5 DIFFERENCE OF LEVEL
For raw sewage, actually produced only in France

source: Aquasaf



PAVITR
IRIDRA

FRB Design

2. FRB and VF – feeding distribution

By submersible pumps:

- Centrifugal for wastewater application
- High solids passage
- Implementation possible in every conditions
- High flow rate to consent uniform distribution on the beds
- Limited energy consumption

source: Xylem

FRB Design

2. FRB – feeding distribution

1st stage → avoid pipe clogging (high flow rate, min dimension 90 mm, no holes)

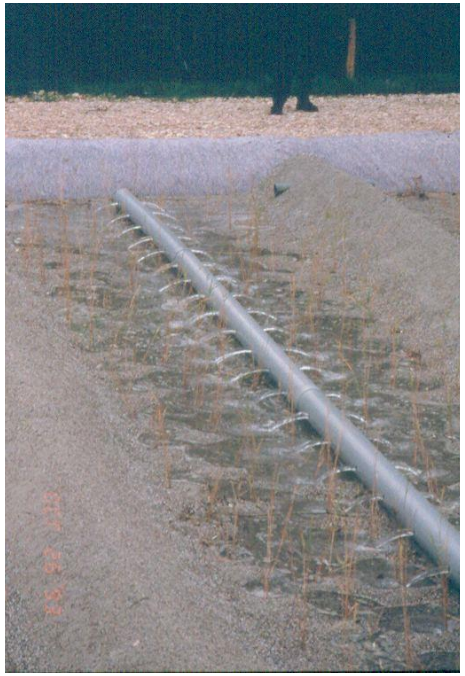
First stage of treatment

source: ECOBIRD

FRB Design

2. FRB – feeding distribution

2nd stage → finer distribution (less clogging risk)



Second stage of treatment

source: ECOBIRD

FRB Design

2. FRB – feeding distribution

Valves for alternative feeding

- Knife gate valves are suggested
- Manual operation (need operator 2 times x week)
- Automatic operation (electric or pneumatic actuator), but need more maintenance and PLC

source: Morbihan Conseil General - SATESE, Étude 2008
Filtres plantés de roseaux Réalisation et fonctionnement dans le Morbihan2008

FRB Design

2. FRB – vegetation

- Phragmites australis

- Canna Indica, Heliconia Psitticorum, Cyperus Alternifolius (Umbrella plant) positively tested in tropical climates (Molle et al, 2017)

FRB Design

2. FRB – others

- Drainage → Perforated pipes

- Ventilation → chimney of aeration

- Waterproof

source: Morbihan Conseil General - SATESE, Étude 2008
Filtres plantés de roseaux Réalisation et fonctionnement dans le Morbihan2008

FRB Design

PAVITR

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 inert material, such as sand (only for VF second stage) and gravel (**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

IRIDRA

FRB Design

Filling media in France

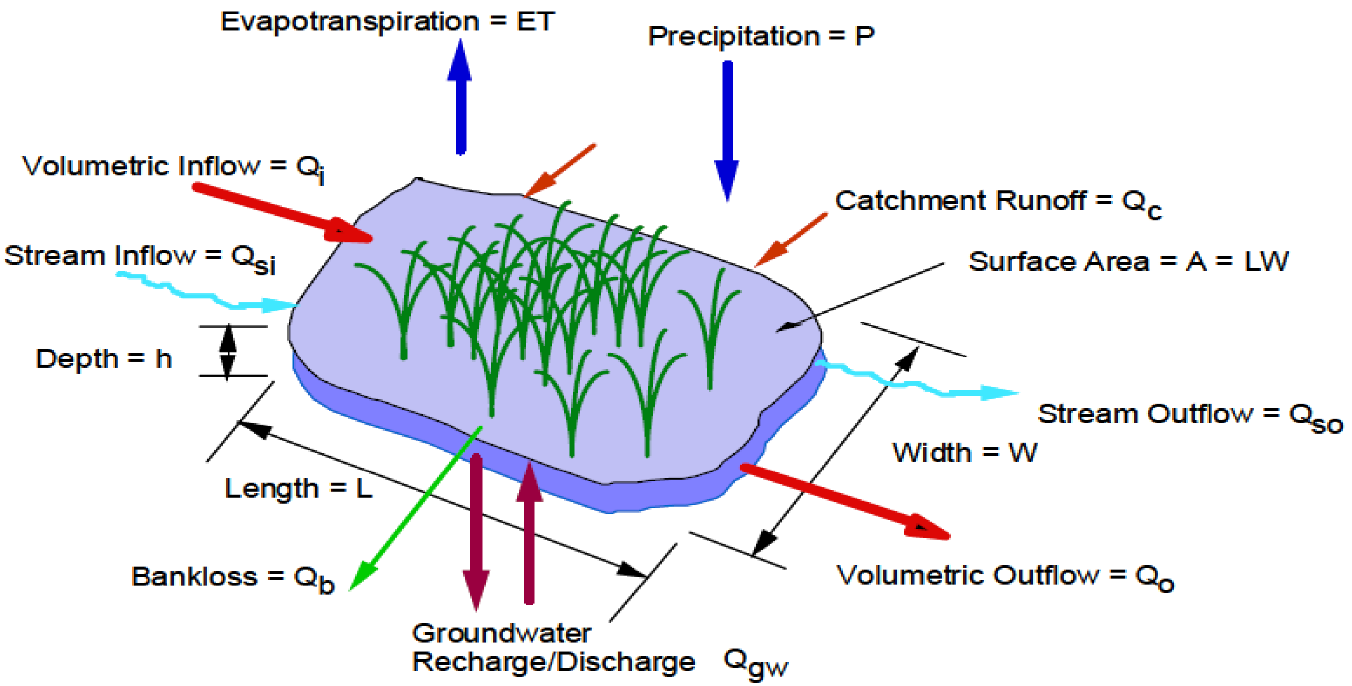
	First stage FRB	Second stage VF
First layer 30 to 80 cm	Gravel 2-4 mm 2-6 mm 3-6 mm	Sand $0.25 < d_{10} < 0.4$ mm $CU = d_{60}/d_{10} < 5$ $d_3 > 63$ µm
Transition layer 10 to 20 cm	6-15 mm 5-10 mm	5-10 mm
Drainage layer 20 to 30 cm	10-20 mm 20-40 mm 20-60 mm	20-40 mm

Source: Pascal Molle , Irstea - Lyon

FRB 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

FRB Design

PAVITR

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

IRIDRA S.r.l.

FRB Design

Design criteria: hydrology

Water mass balance components in a CW (simplified):

$$Q_o = Q_i + PA - EA$$

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

FRB Sizing methods

Loading charts

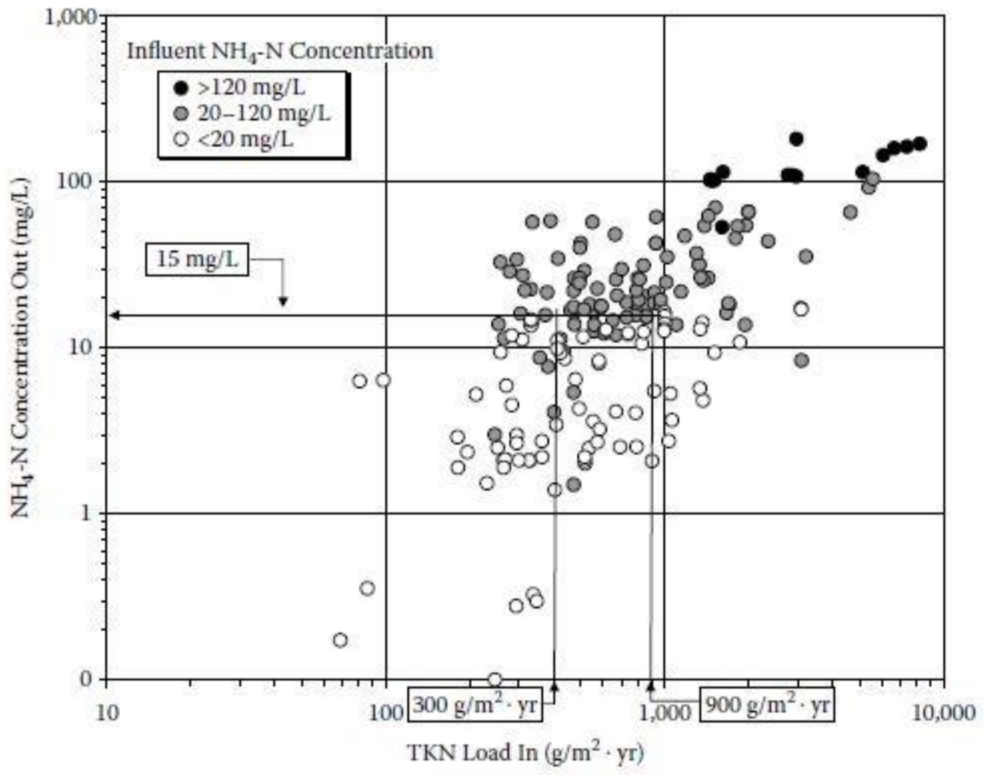
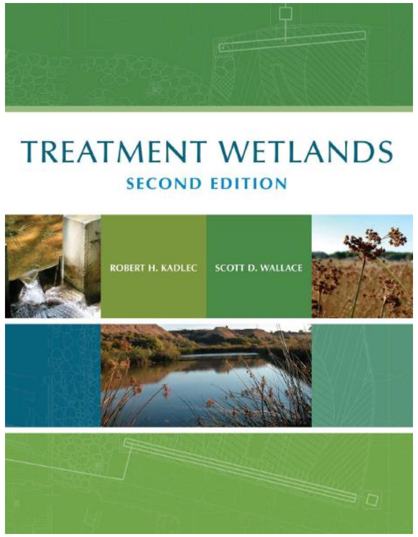


FIGURE 20.1 TKN–Ammonia loading chart, with forecasted treatment performance.



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

PAVITR

IRIDRA

Key learning points…

PAVITR

- FRB: vertical flow system for the treatment of raw sewage
- NO primary treatment
- Sludge reuse
- Two stages: 1st FRB, minimum 3 sectors; 2nd VF or HF CW
- 1-3 cm/year sludge accumulation
- Sludge removal every 10-15 years
- Components: inlet and outlet piping, waterproof liner, filter media, vegetation, berms

- Pre-treatment → FRB → VF/HF → discharge/reuse
- Feeding cycle: 3-4 days feeding, 7 days resting, alternate
- Area: 1-2 m2/PE 1st stage; 0.8-1.5 m2/PE 2nd stage (VF)
- Filter bed: 2-6 mm gravel (30-80 cm), 5-15 mm gravel (10-20 cm), 20-60 mm gravel (20-30 cm)
- HLR: up to 0.37 m/d (single bed)
- OLR: 300-400 gCOD/m2/d (single bed)

Let’s have a break

We will be back in 15 min

Construction and implementation

FRB 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

FRB implementation

Implementation phases

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

FRB implementation

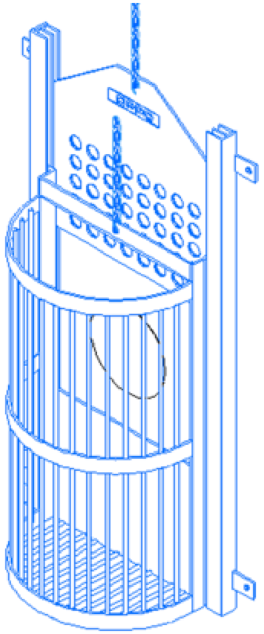
1. Earthmoving

- 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

FRB implementation

0. pre-treatments

Pretreatment – manually cleaned screening



Pretreatment – mechanically cleaned screening

Source: IRIDRA

FRB implementation

1. Earthmoving

Site cleaning

Excavation and embankments

Source: IRIDRA

FRB implementation

1. Earthmoving

Excavation and terracing

Excavation and embankments

Source: IRIDRA

FRB implementation

1. Earthmoving

Excavation for concrete works

Reshaping of the area

Source: IRIDRA

FRB implementation

2. Waterproofing

1st geotextile layer

Sand layer

Source: IRIDRA

FRB implementation

2. Waterproofing

Geomembrane

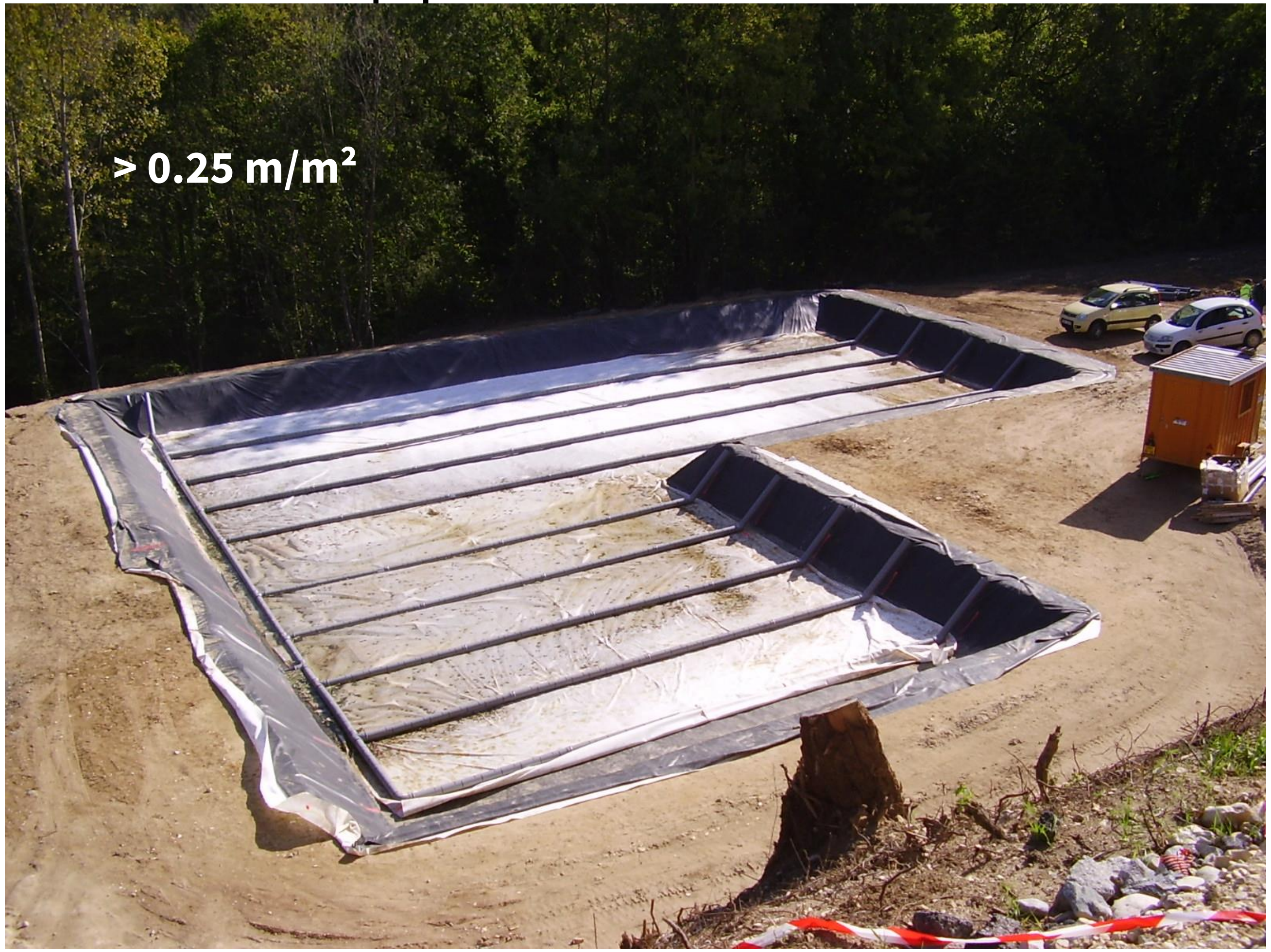
2nd geotextile layer

Source: IRIDRA

FRB implementation

4. Construction details

Drainage and passive Aeration pipes



Source: Pascal Molle , Irstea - Lyon

FRB implementation

4. Construction details

Drainage

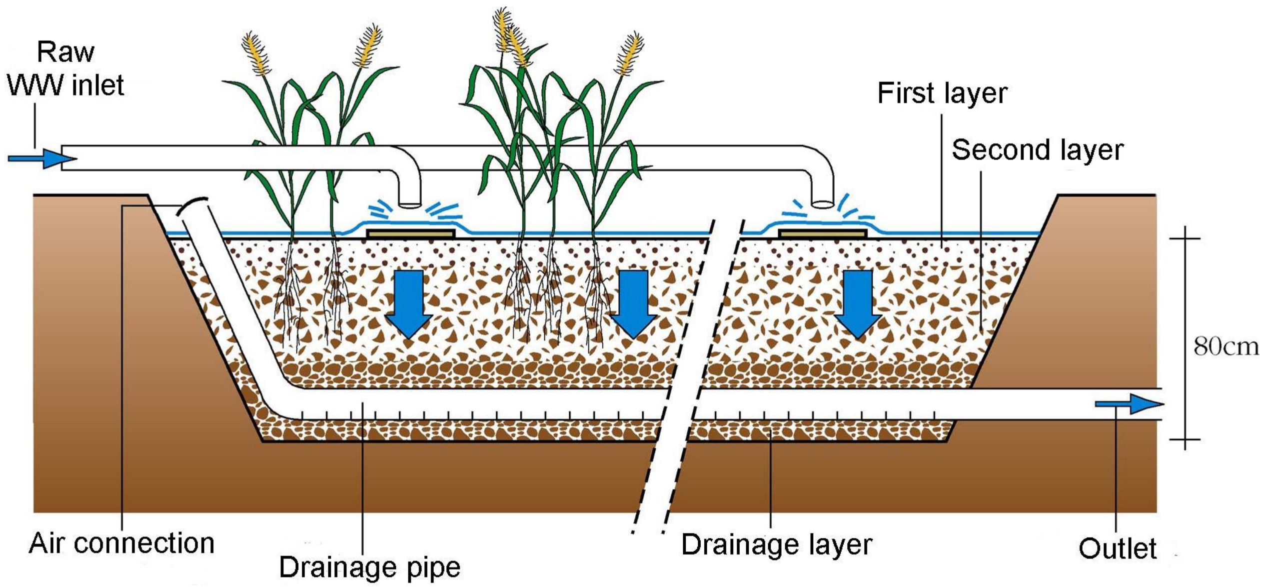
Source: IRIDRA

FRB implementation

3. Filling beds

Recommendations:

- As much as possible according to literature indications
- Well cleaned
- Possible rounded grain



Source: IRIDRA

FRB implementation

PAVITR

3. Filling beds

Source: IRIDRA

IRIDRA S.r.l.

FRB implementation

4. Construction details

FRB Feeding system

Source: ECOBIRD

FRB implementation

5. Construction details

VF pumps and siphons

Source: IRIDRA

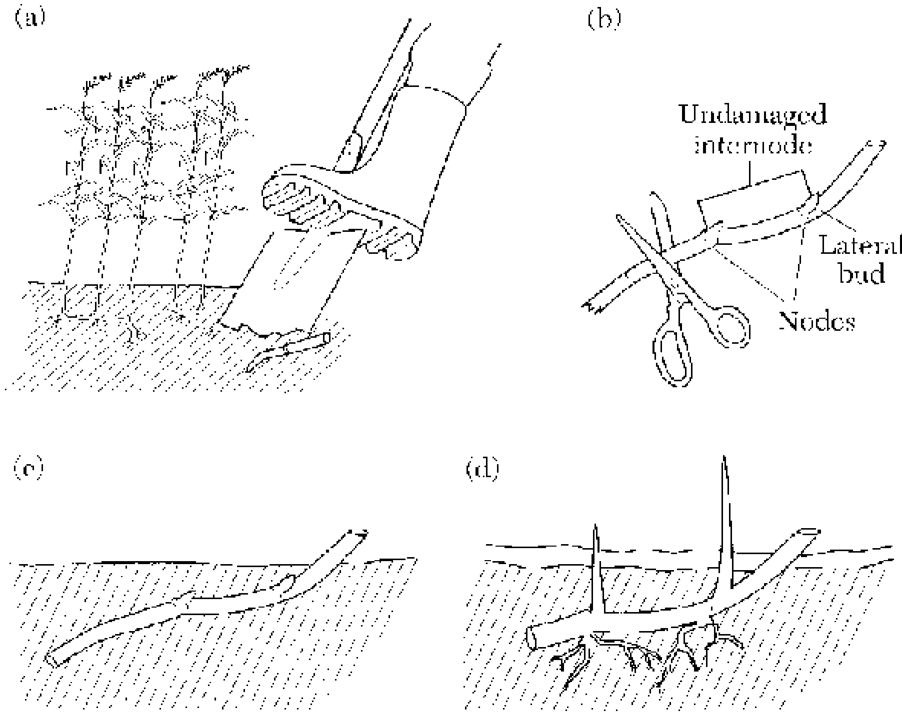
Source: Aquasaf

IRIDRA

FRB implementation

5. Planting and starting phase

Dig preparation for plants



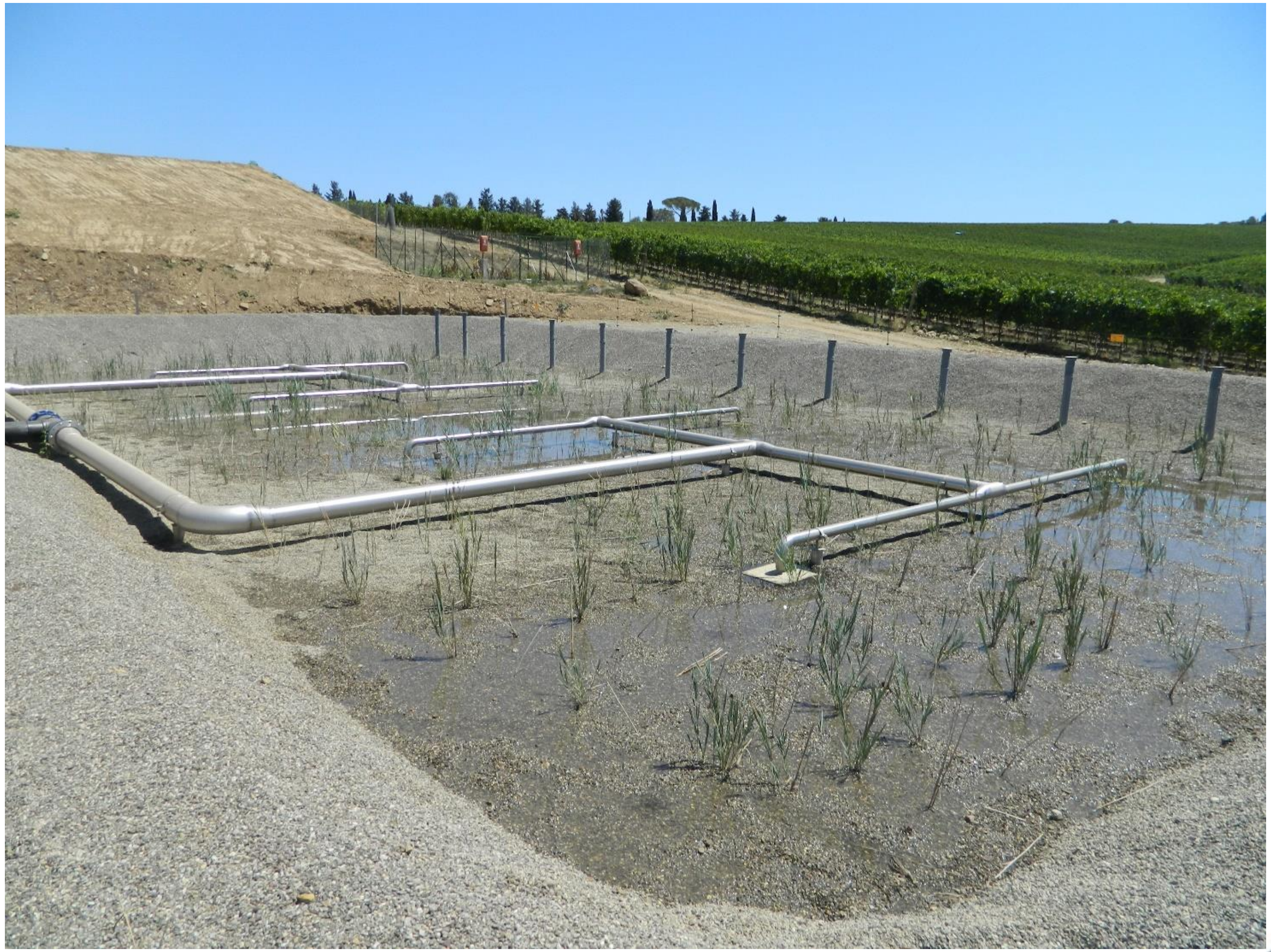
Rhizome

Pot plants

FRB implementation

5. Planting and starting phase

Bed flooding



Source: IRIDRA

Key messages

- Earthmoving: reed bed, piping, concrete tanks
- Pre-treatment
- Waterproofing: 1st geotextile layer, sand layer, geomembrana, 2nd geotextile layer
- Drainage system: slotted pipes
- Passive aeration pipes
- Bed filling: clean, round gravel
- Feeding system
- Vegetation 1st stage: *Phragmites australis (some other alternatives are possible in tropical climates)*
- Dig preparation
    - Planting
    - Bed flooding

Source: IRIDRA

Source: ECOBIRD

Operation and maintenance

Operation & Maintenance

PAVITR

O&M requirements 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.

IRIDRA

Operation & Maintenance

Malfunctioning in the system

- Clogging of the medium or of the inlet and outlet devices (presence of puddles and stagnant water on the surface for long time, reduced permeability)
- No functioning of pumps or siphon if present
- Solid escape from primary treatment
- Hydraulic overload
- Solid overload
- Organic overload
- Incorrect plant management

Operation & Maintenance

Malfunctioning in the system - clogging

FRB

FRB system is "designed" for clogging, so the clogging has to be intended as a strong reduction in permeability rate that doesn't permit the drainage of the wastewater. In the case that the permeability rate should be lower than 0.3x10-4 m/d, the emptying prognosis should be revised

VF (if selected for second stage)

Immediate action has to be taken in the case of clogging. A VF can recover well after a resting period of two-three weeks in sunny and dry season, where the filter bed can dry out. Once clogged, a VF system does not recover without resting periods.

If clogging occurs, the procedure is to disconnect the clogged line for a period of 3 weeks.

Operation & Maintenance

PAVITR

Start-up and commissioning

A newly built wetland is not in a condition to perform the design goals and the operative standard conditions. Start-up phase is not brief, because it can take considerable time for the wetland biology to develop; it is expected that removal will be enhanced after the plants will cover totally the wetland surface.

- **Organic removal** high once that the biological film is established (normally after 2-3 weeks).
- **removal of TSS** reaches immediately max, if the filling media is well washed.
- Maximum removal of **surfactants** after the complete growth and diffusion of the plants at the end of the second growing season; in the first 1-2 year a low formation of scum could be observed in the effluent.
- **Nitrification**: in VF stage reaches rapidly a good efficiency, due to the constant presence of available oxygen in unsaturated conditions. In FRB stage the maximum efficiency will be observed after the complete growth and diffusion of the plants and the establishment of a sludge layer of approximately 2-4 cm with aerobic bacterial communities (after 1-2 year)
- **Denitrification**: after at least 2 year with the complete diffusion of plants, where the up-take of nitrogen reaches the highest and a sufficient quantity of carbon source is available

IRIDRA

Operation & Maintenance

Vegetation start-up

Phase 1

maintain the water level minimum 10 cm below the gravel surface to permit the initial planting or for replanting

Phase 2

increase the water depth until approximately 5 cm above the gravel surface (opening the upper plug in the regulation device and closing the other plugs) for about 1 month: the emergent shoots should be above the water surface at all times to give the plants access to sunlight and oxygen.

Phase 3

Setting the water level at the design standard depth after plants are established

Operation & Maintenance

PAVITR

FRB sludge strategy

Start-up and commissioning phase

Commissioning phase duration depends by climate conditions, time of plantation, loading strategies, sludge quality.

- **Initially in dry climates** 2 days of feeding and 4 days of resting can be considered

Standard operation

- **3.5 days of feeding and 7 days of resting**

If the alternation is manually operated, an operator has to visit the plant twice a week for valves setting.

IRIDRA S.r.l.

Operation & Maintenance

PAVITR

FRB emptying

- Registrations of the sludge **residue height** and of the average **Organic and solids Loading rates** (KgBOD/m2 x day and KgSS/m2 x day) since commissioning
- Estimation of **sludge layer growing rate** on the basis of the expected loading rates.
- **Max admitted level of sludge in a basins**: **15-25 cm**, or when the decrease of the permeability rate lead to poor drainage of the basin and decrease of performance in nitrification

Composting period (the period that we have to excluded a sector before emptying to permit the maximum dewatering); it depends by climatic conditions, Phragmites diffusion, loading strategies, loading rate

Generally at least 1 months before emptying during dry season

IRIDRA

PAVITR

Operation & Maintenance

FRB sludge emptying

Source: Molle, 2006

IRIDRA

Operation & Maintenance

FRB re-establishment

The re-establishment phase begins after emptying. It is expected that the vegetation will establish itself more rapidly and therefore the loading during the first year in a new operating phase can follow standard operations.

No re-plantation of reeds is needed during this phase

Source: Molle, 2006

Operation & Maintenance

PAVITR

Sludge disposal

The final product "mineralized sludge" is a crumbly, light brown-colored material with a typical earthy smell. In case of civil wastewater treatment, the analysis on sludge composition shows generally the possibility of **reuse for agricultural purpose** (soil conditioner). The sludge final composition depends on influent quality: in this case the inflow wastewater is partially domestic and partially industrial and the industrial wastewater is produced by food processing activities and consequently their characteristics are very similar to domestic wastewater, so the final sludge can probably reach the goal of sludge agricultural reuse. However the sludge won't contain hazardous compounds and it can be disposed in landfills that receive inert materials.

IRIDRA

Operation & Maintenance

PAVITR

Example of O&M plan

Operation	Minimum frequency
1. Check of inlet and outlet device 2. Check of water level 3. Verification of the functioning of electro-mechanical tools 4. Check of weed and weeding during the first year 5. Check of eventual bad odor	Every 30 days
Verification of system functioning by means of analysis of inlet and outlet flows	Monthly or seasonal
Plant cutting	Annual

IRIDRA

Key messages

- Simple operation and management
- No high tech appliances
- No chemical additives
- Periodic control of inlet, outlet
- Check pump and siphon
- Check for clogging (permeability rate < $0.3*10^{-4}$ m/d)
- Plant harvesting
- Standard operation: 3.5 days of feeding and 7 days of resting
- Max sludge level: 15-25 cm
- Composting period: min 1 month

Source: IRIDRA

Example:
the PAVITR pilot project

Introduction

Objective

To analyze the effect of irrigation with treated domestic wastewater by FRB adapted to local conditions

Location

The present research is conducted at **SWINGS site Aligarh Muslim University, Aligarh, Uttar Pradesh, India**

Materials & Method

PAVITR

Wastewater Treatment System

Urban wastewater is collected after pretreatment from Aligarh **Sewage Treatment Plant** (STP); in the SWING site there are more than 10 different pilots loaded with the same type of wastewater

Flow: 50-100 m^3/d depending on the pilot monitoring results

Total investment cost (CAPEX): 35,000.00 USD

STP

Equalization tank
With pump

Constructed wetland
(FRB)

Tertiary treatment
(disinfection)

Reuse for irrigation

IRIDRA S.r.l.

Materials & Method

FRB

The French reed bed design was adapted to the target and local conditions

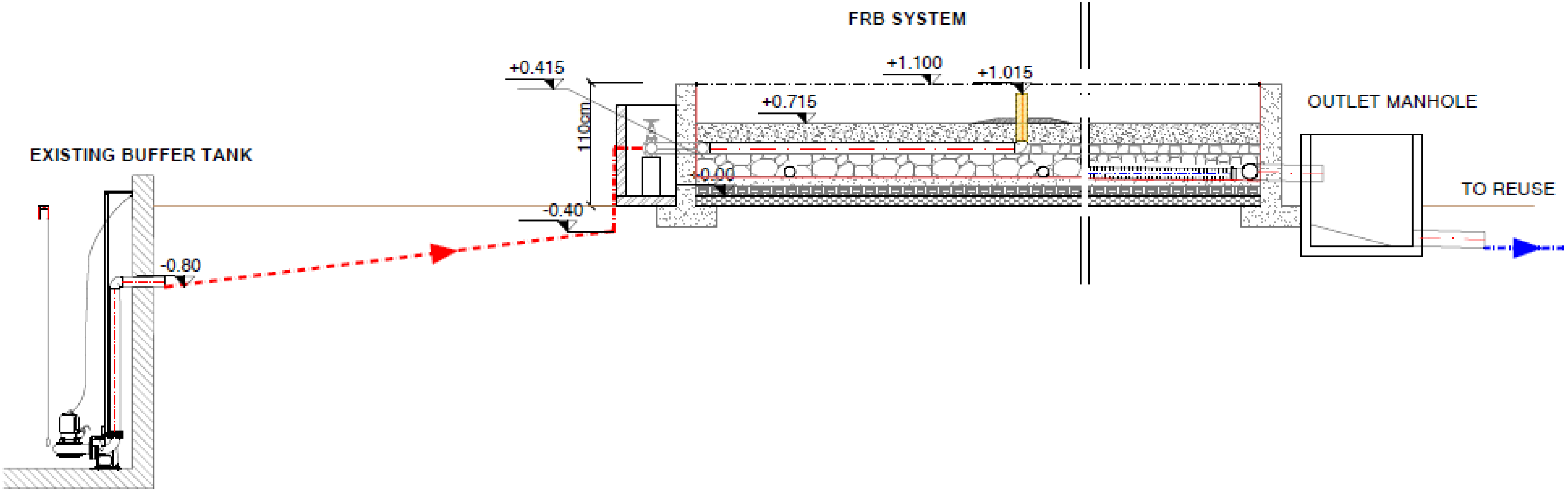
The aim is to reuse for land irrigation, so to keep nutrients inside, filtration height was minimized to 20 cm, permitting anyway a good removal of organic matter and suspended solids. This permits also to reduce cost and gravel transportation (which is supplied from quarries located about 300 Km away, because in the region there is only sand and loamy soil.

Parameters	Dimensions	
Depth of filter media from bottom ● Crushed Gravel (20-30 mm) drainage ● Crushed Gravel (10 mm) transition ● Crushed Gravel (2-6 mm) filtration	0.5	m
Bed Size (n°1, divided in 3 sector	250	m2
Type of plants	Phragmites Karka	

Low filtration height → **More nutrients available for irrigation**

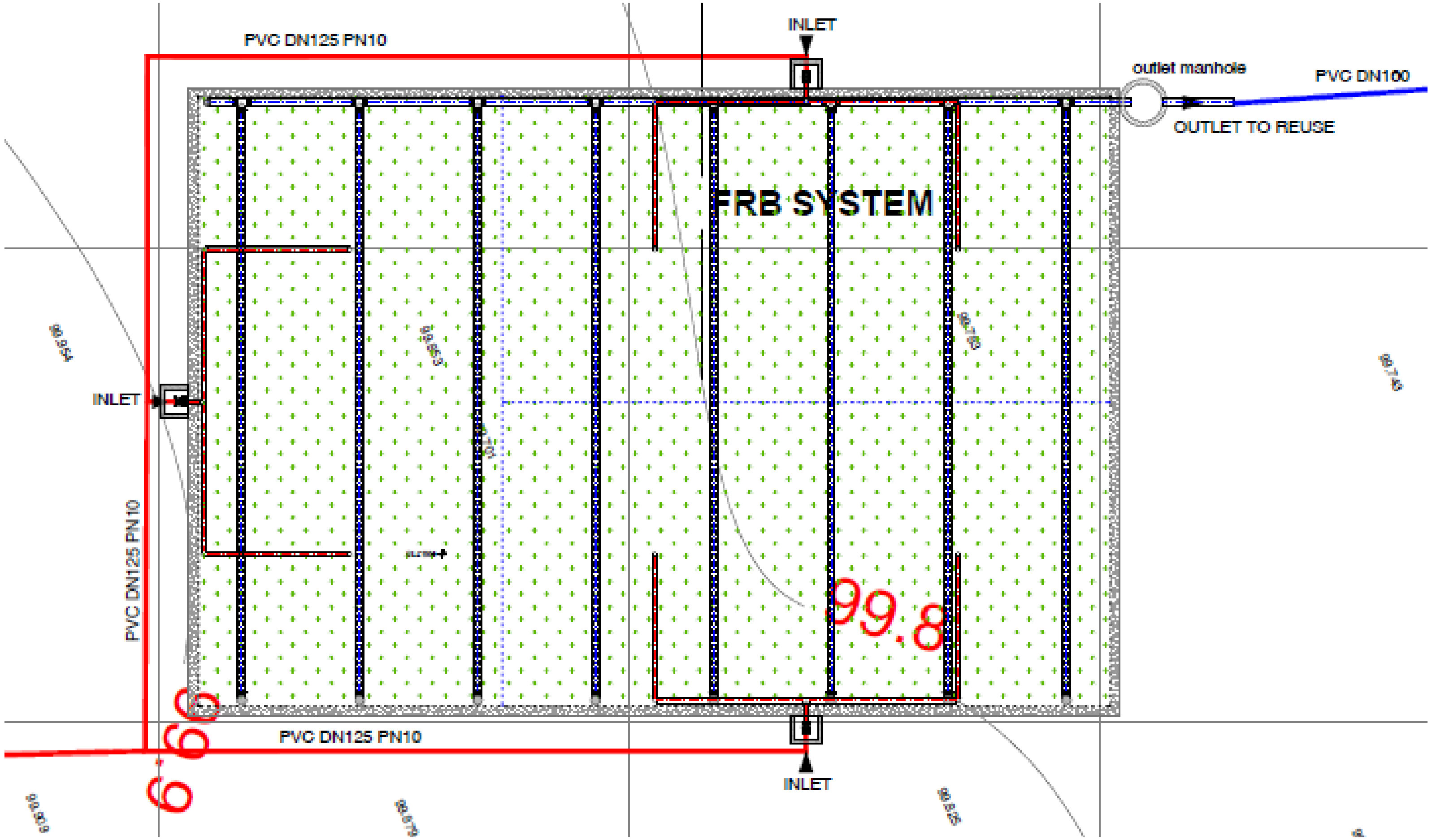
Materials & Method

FRB – Process scheme



Materials & Method

FRB – Layout



Materials & Method

FRB under construction (May 2023)

Key messages

- Adaptation of design to local conditions is always needed for small works done by local contractors with limited skilling and economical capacity. Local market generally offer cheaper materials that not always are acceptable and they can compromise the functionality of the plant. On the other hand, “creativeness” and capacity of adaptation of local workers is a resource to take in account in India by designer and supervisors, which however have to know very well the design and possible issues during operation and maintenance.
- Waterproofing of the bed is one of the most critical point, because for small works it is too costly and too long to provide HDPE 1-2 mm liners thermo-welded on site by professional workers. Local market is poor of alternative solutions, offering Tarpoulin and other material with low characteristics and difficult to join on site in a safe way. On the other hand, the designed FRB is totally drained on the bottom by several drainage pipes during operation and the risk of leakage is minimum. Increase the density of drainage pipes can help in minimizing leaking risk and increasing passive aeration of the bed.
- Construction is on going, the system will be completed by the end of June; reeds will be provided by a nursery but they are available only during monsoon period (before it is too dry). Loading with wastewater and monitoring will start when plants will be well extablished, probably in August-September.

Homework

Introduction

Design a FRB wetland for a small community (**100 PE**) in a temperate climate.

Effluent targets are:

- BOD5: **20 mg/L**
- COD: **90 mg/L**
- TSS: **15 mg/L**
- TKN: **15 mg/L**

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

Key data for calculations

PAVITR

- Average wastewater generation per PE: 150 L/d
- Average daily mass loadings per PE: 150 g COD, 60 g BOD, 70 g TSS, 12 g TKN
- First stage: 3 units
- Second stage: VF, 2 units
- Liquid layer: 2 – 5 cm (assume 3 cm)

Key data for calculations

Maximum design loads for classical FRB wetland design. Values given are per square meter of bed in operation.

Treatment Stage	HLR ($m^3/m^2 \cdot d$)	COD ($g/m^2 \cdot d$)	BOD_5 ($g/m^2 \cdot d$)	TSS ($g/m^2 \cdot d$)	TKN ($g/m^2 \cdot d$)
First stage	0.37	350	150	150	30
Removal [a]		$0.80 \times M_i$	$0.90 \times M_i$	$0.90 \times M_i$	$1.1128 \times M_i^{0.8126}$
Second stage	0.37	70	20	30	15
Removal [b]		$0.75 \times M_i$	$0.80 \times M_i$	$0.80 \times M_i$	$1.194 \times M_i^{0.8622}$

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 loads and influent concentrations.

2. Calculate the FRB area based on the treatment targets.

Solution – 1st stage

PAVITR

1. Calculate the inflow, organic load and influent concentration

- Inflow: 15 m3/d
- Organic load: 6000 gBOD/d; 15000 gCOD/d; 7000 gTSS/d; 1200 gTKN/d
- Influent concentrations: 400 mgBOD/L; 1000 mgCOD/L; 467 mgTSS/L; 100 mgTKN/L

2. Calculate the FRB area based on the treatment target

- Area: 45 m2 per unit, 135 m2 total
- Batch volume: 1 m3/batch, n° batches: 15

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

Solution – 2nd stage

PAVITR

1. Calculate the inflow, organic load and influent concentration

- Inflow: 15 m3/d
- VF influent concentrations: 40 mgBOD/L; 200 mgCOD/L; 47 mgTSS/L; 41 mgTKN/L

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

- Area: 50 m2 per unit, 100 m2 total

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

References

- CORDIS (2016): Safeguarding Water resources in India with Green and Sustainable technologies SWINGS. Final report summary. Luxenbourg: Community Research and Development Information Service (CORDIS). URL: https://cordis.europa.eu/project/id/308502/reporting [Accessed: 26.07.2021]
- DOTRO, G., LANGERGRABER, G., MOLLE, P., NIVALA, J., PUIGAGUT, J., STEIN, O., & VON SPERLING, M. (2017): Treatment wetlands (=Biological Wastewater Treatment Series, Volume 7). London: IWA publishing. URL: https://www.iwapublishing.com/sites/default/files/ebooks/V7%20Treatment%20Wetlands.pdf [Accessed: 26.07.2021]
- MOLLE P., LIÉNARD A., BOUTIN C., MERLIN G., IWEMA A. (2005): How to treat raw sewage with constructed wetlands: An overview of the French systems. In: Water Sci Technol. 2005, 51(9), 11-21. London: IWA Publishing. URL: https://iwaponline.com/wst/article-abstract/51/9/11/11752/How-to-treat-raw-sewage-with-constructed-wetlands [Accessed: 26.07.2021]
- RIZZO, A., BRESCIANI, R., MARTINUZZI, N., & MASI, F. (2018): French reed bed as a solution to minimize the operational and maintenance costs of wastewater treatment from a small settlement: an Italian example. In: Water, 10(2), 156. Basel: MDPI. URL: https://www.mdpi.com/2073-4441/10/2/156/htm [Accessed: 26.07.2021]

Credits

This training has been created in the framework of the EU-Indian Joint Project "PAVIRT- Potential and Validation of Sustainable Natural & Advance Technologies for Water & Wastewater Treatment, Monitoring and Safe Water Reuse in India". This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No821410 and the Department of Sciences and Technology of India under the Grant DST/IMRCD/India-EU/Water Call2/PAVITR/2018 (G).

For more information, please visit: https://pavitr.net