TWO DAYS TRAINING ON THE OPERATION AND MANAGEMENT OF WWTPS

9-10 September, Murcia

Design for Soft Technologies for Small and Rural WWTPs

Presented by: Dr. Carlos Aragon

Table of contents

1. Introduction to the design of soft technologies

- ✓ Extensive technologies are good wastewater treatment solutions for small and rural populations with lack of economic resources.
- ✓ They required a long surface for their implementation but no energy supply (or minimum).
- ✓ Main misunderstandings:
  - ✓ "Simple maintenance and operation" ≈ "Simple design and construction".
  - ✓ " Low running costs ≈ "nil cost, the WWTP works alone".

1. Introduction to the design of soft technologies

Overload in a facultative pond

Clogging in Horizontal Constructed Wetland

Overload in a Intermittent Sand Filter

Table of contents

2. Design and construction of Constructed wetlands

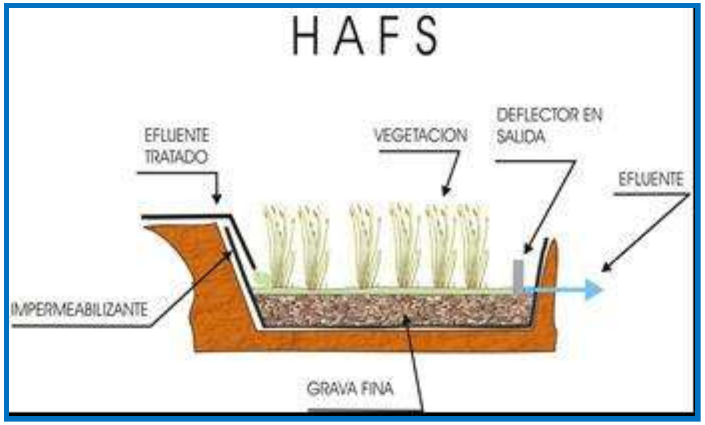
Vertical flow CW

Combination of CW

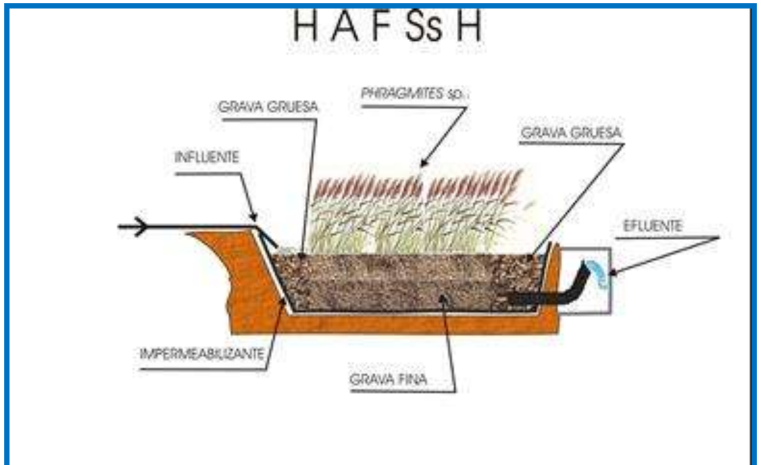
Horizontal flow CW

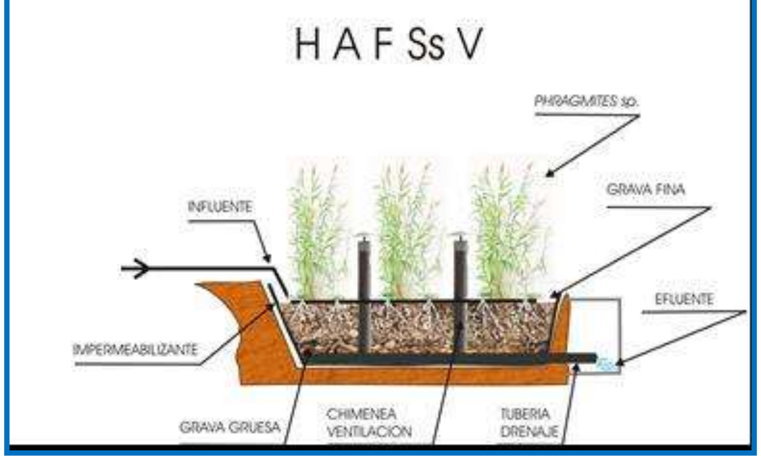
2. Design and construction of Constructed wetlands

Surface flow CW



Subsurface flow CW (horizontal and vertical)

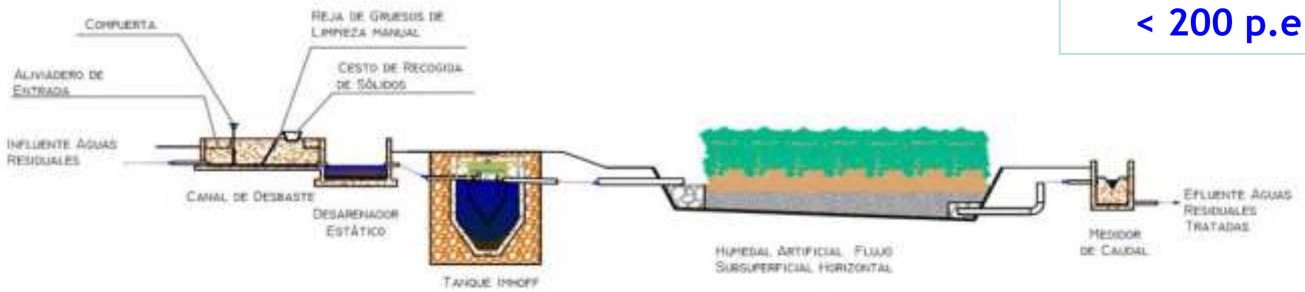




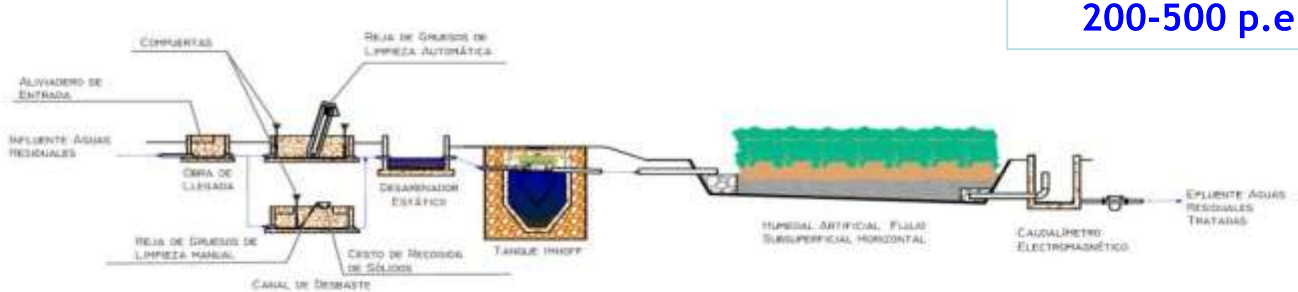
2. Design and construction of Constructed wetlands

Horizontal flow CW: flow diagrams

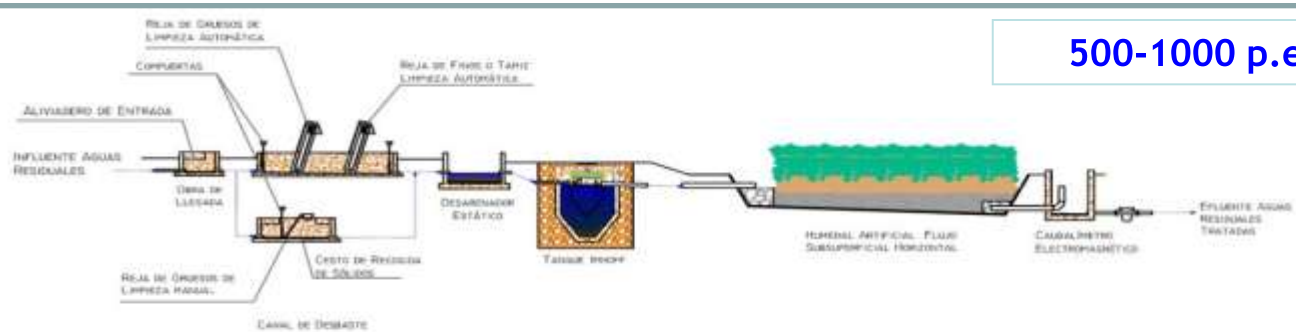
< 200 p.e.



200-500 p.e.



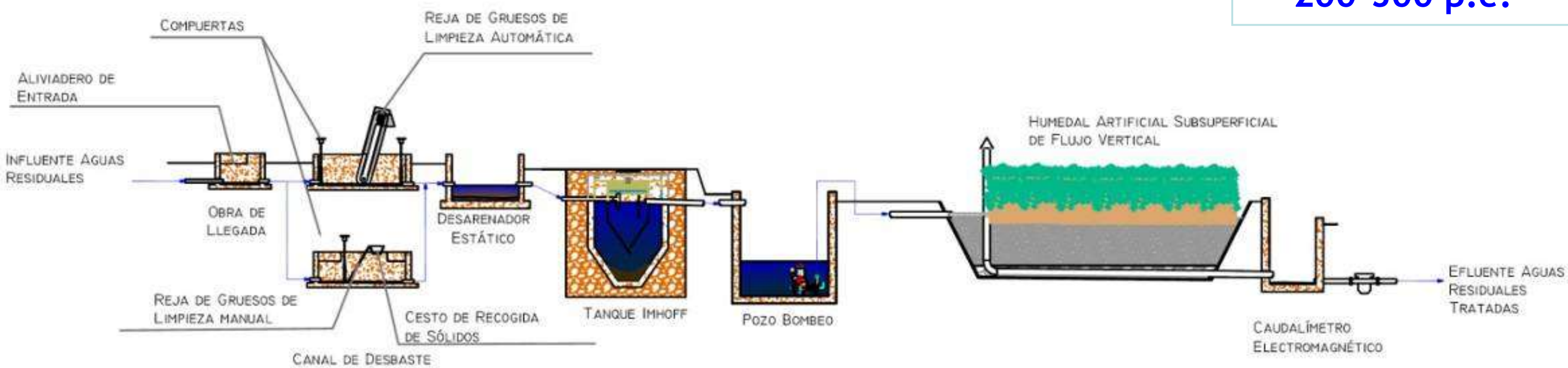
500-1000 p.e.



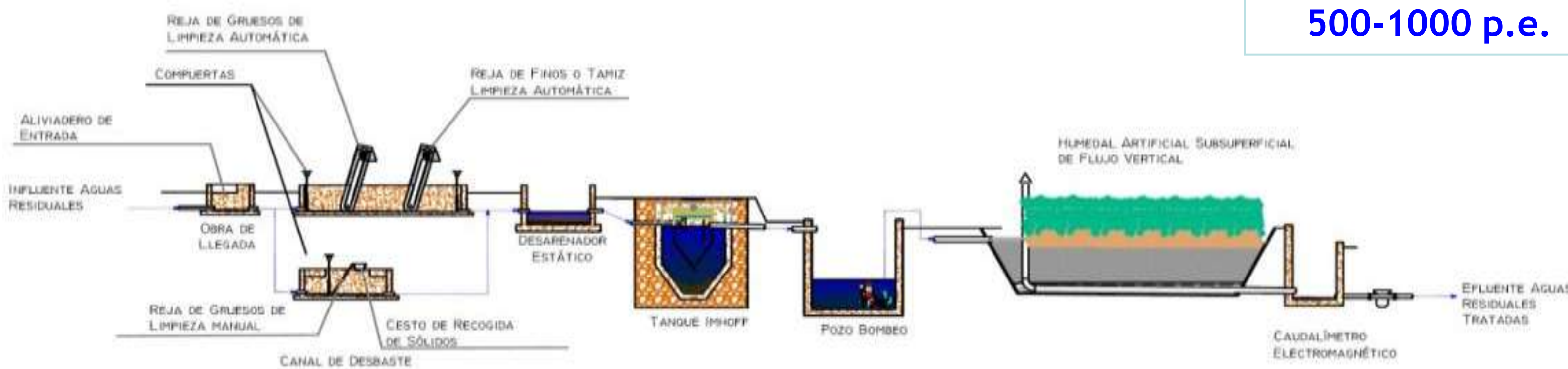
2. Design and construction of Constructed wetlands

Vertical flow CW: flow diagrams

200-500 p.e.

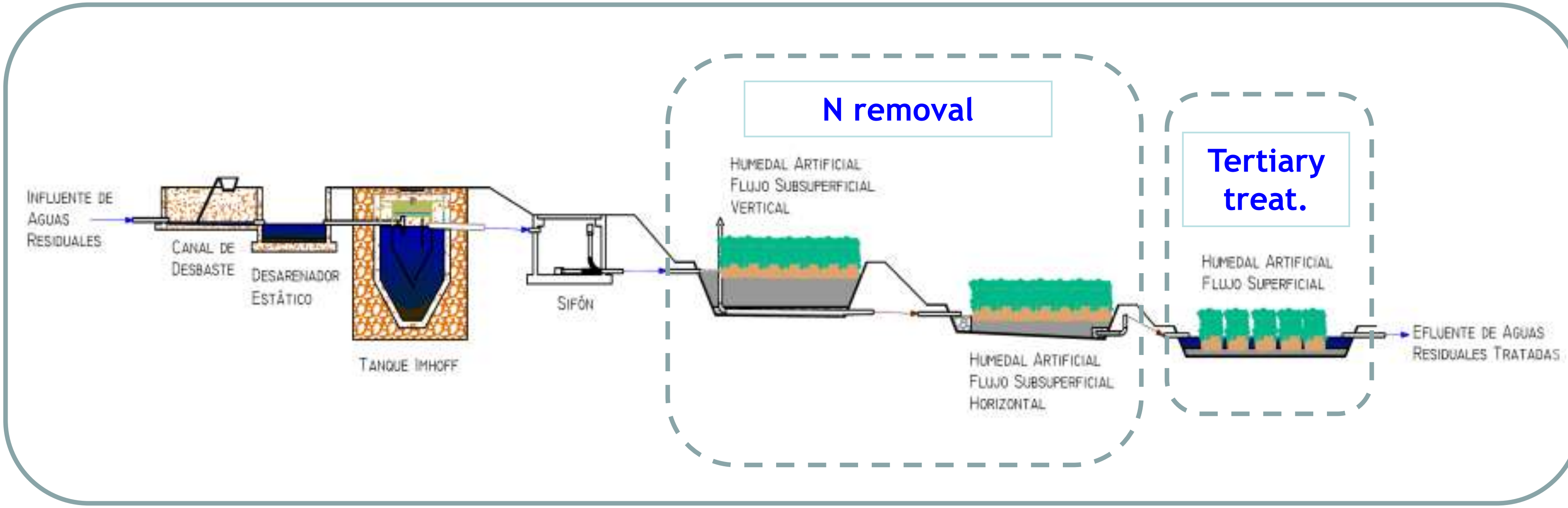


500-1000 p.e.



2. Design and construction of Constructed wetlands

Combination of CW: vertical CW + horizontal CW + surface flow CW



2. Design and construction of Constructed wetlands

Surface flow and horizontal flow CW

$$S = L \times A = \frac{Q \times \ln(C_i / C_e)}{K_T \times h \times \varphi_s}$$

S: planted surface (m^2)

L: lenght (m) A: width (m)

Q: flow rate (m^3/day)

C_i: inlet pollutant's concentration (mg/l). The performance of the primary treatment must be taken into account.

C_e: pollutant's concentration at the effluent(mg/l)

K_T: constant (d^{-1})

h: depth of water column (m). 0.3-0.4 m in Surface flow CW and 0.4 - 0.6 m in Horizontal flow CW.

φ_s: porosity of the filtering bed (parts per unit).

- ✓In sufarce flow CW it varies from 0.65 to 0.75, depending on the level of growth of vegetation.
- ✓In horizontal flow CW, the porosity depends on the gravel size and its given in charts.

2. Design and construction of Constructed wetlands

Surface flow and horizontal flow CW

K_T varies with the temperature as follows:

$$S = L \times A = \frac{Q \times \ln\left(C_i / C_e\right)}{K_T \times h \times \varphi_s}$$

$$K_T = K_R \cdot \theta_R^{(Tw - Tr)}$$

Where:

K_R: constant at the referenced temperature (d^{-1})

T_w: water's temperature (°C). Usually, the average temperature of the coldest month.

T_r: referenced temperature (°C) employed for the determination of the coefficient θ_R, normally 20 °C

θ_R: temperature coefficient (dimensionless)

Values of K_R and θ_R, for different pollutants

Pollutant		BOD_5	NH_4^+ Nitrification	NO_3^- Denitrification
Surface flow CW	K_R (d^{-1})	0.678	0.2187	1
	θ_R	1.06	1.048	1.15
Sub-surface Horizontal flow CW	K_R d^{-1})	1.104	$0.01854 + 0.3922\ (h_r)^{2.6077}$	1
	θ_R	1.06	1.048	1.15

h_r: depth of the gravel bed with rhizome (m)

2. Design and construction of Constructed wetlands

Surface flow and horizontal flow CW

Sometimes, the equation

$$S = L \times A = \frac{Q \times \ln(C_i / C_e)}{K_T \times h \times \varphi_s}$$

Is expressed as:

$$S = L \times A = \frac{Q \times \ln(C_i / C_e)}{K_A}$$

Where $K_A = K_T \times h \times \varphi_s$ (m/d)

For BOD_5 removal it is recommended a K_A = 0.08 m/d, meanwhile if nitrogen removal is required, the recommended value of this constant is 0.025 m/d.

The above values are applicable when BOD_5 at the effluent of the primary treatment is ≤250 mg/l. When it is > 250 mg/l K_A should be reduced by 20%.

2. Design and construction of Constructed wetlands

Surface flow and horizontal flow CW

The required surface is determined taking into account empirical data. Normally, a organic load of approximately 14 $gBOD_5/m^2$.day is employed in the design of Horizontal flow CW.

1. **Knowing the wastewater flow rate to be treated (m^3/d) and the concentration of BOD_5 (g/m^3) in the influent, the product of both terms is the organic load applied to the CW (g BOD_5/d).**
2. **Taking into account the performance of the primary treatment (around 30%), the organic load to be treated in the CW is the inlet organic load multiplied by 0.7.**
3. **Dividing this organic load by the recommended organic load, the surface required for the implementation (m^2) is obtained.**

Example:

Initial data: Q = 40 m^3/d BOD_5 = 305 mg/l (= 305 g/m^3)

Organic load= 40 m^3/d x 305 g BOD_5/m^3 = 12200 g BOD_5/d (203 p.e.)

Organic load at the exit of the primary treatment = 0.7 x 12200 g BOD_5/d = 8540 g BOD_5/d

CW surface = = 8540 g BOD_5/d /14 g BOD_5/m^2.d = 610 m^2

2. Design and construction of Constructed wetlands

Recommended values for CW

Designing parameters for surfaceFlow Constructed Wetlands (Metcalf & Eddy, 2000)

Parameters	Value
Hydraulic retention time (d)	4-15
Water depth (m)	0.1-0.4
Organic load (kg BOD_5/ha.d)	≤ 67
Hydraulic load (m^3/m^2.d)	0.014-0.046

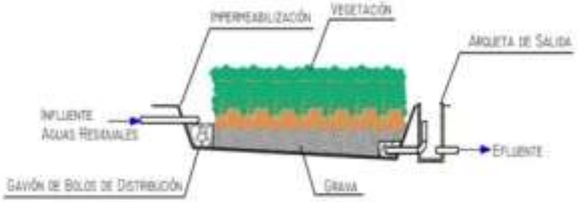
Designing parameters for SubsurfaceFlow Constructed Wetlands

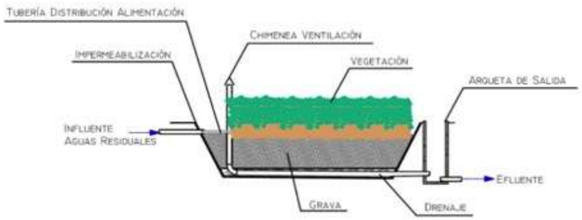
Parameters	Value	
	Horizontal	Vertical
Organic Load (g BOD_5/m^2.d)	8*	14*
Mean depth of the filter media (m)	0.4-0.6	0.5-0.8

** Considering the effluent of a primary settling unit.*

2. Design and construction of Constructed wetlands

Constructive issues





2. Design and construction of Constructed wetlands

Inlet distribution system

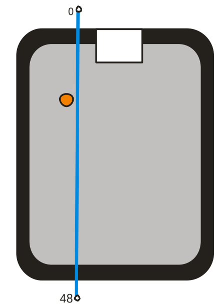
Horizontal Subsurface Flow CW

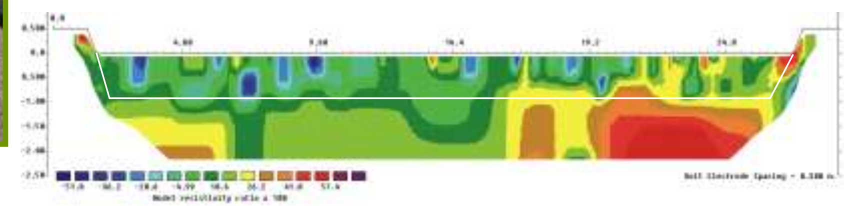
Vertical Subsurface Flow CW

2. Design and construction of Constructed wetlands

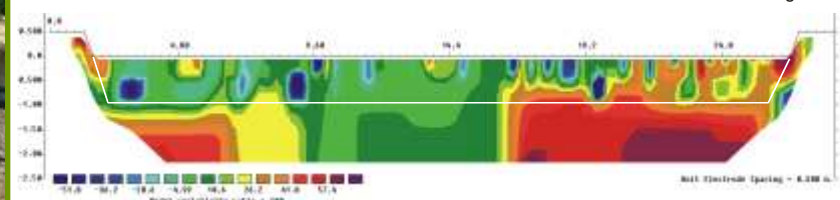
Inlet distribution system

Electric tomography assays

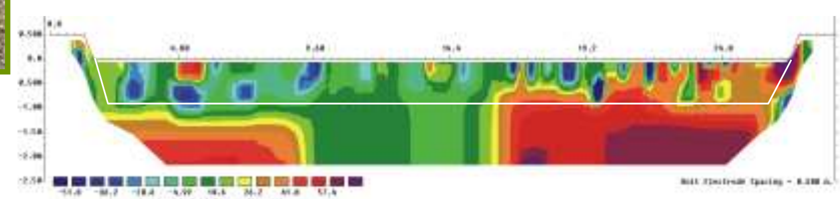




Time=5 min
1 discharge



Time=182 min
4 discharges



Time=333 min
7 discharges

2. Design and construction of Constructed wetlands

Intermittent feeding for Vertical flow CW

Source Rissy Plastics (www.rissyplastics.com)

2. Design and construction of Constructed wetlands

Intermittent feeding for Vertical flow CW

Source: Telcom (www.telcomitalia.it)

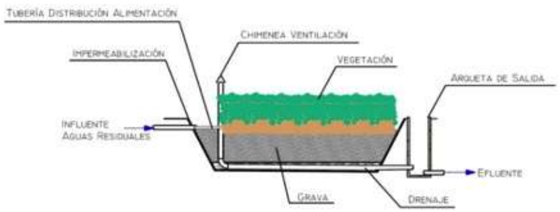
Source: Benito&Cia (www.benitoycia.com)

2. Design and construction of Constructed wetlands

Outlet in Horizontal flow CW

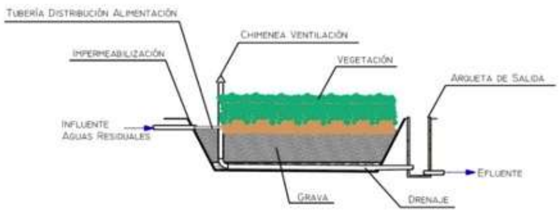
2. Design and construction of Constructed wetlands

Drainage system and outlet in Vertical flow CW



2. Design and construction of Constructed wetlands

Ventilation system in Vertical flow CW



2. Design and construction of Constructed wetlands

Filtering bed media

In subsurface flow CW the filtering media is an essential part of the treatment unit. Its proper selection and positioning determines the performance of the CW, because one of the main risks of such kind of CW is the filtering media clogging.

In Horizontal Subsurface CW a gravel size of *6-12 mm* is recommended. The thickness of the gravel bed in the central point of the CW is *0.6 m*, although it can be lower *0.3-0.4 m*.

In Vertical Subsurface flow CW the thickness of the filtering bed is 1 m and it consists on (from top to the bottom): a 10 cm layer of thick sand, a 70 cm layer of 3-8 mm gravel and a 20 cm layer of 20-32 mm gravel which contains the drainage-ventilation pipes.

2. Design and construction of Constructed wetlands

Positioning of the filtering media

2. Design and construction of Constructed wetlands

Plantation

2. Design and construction of Constructed wetlands

Vegetation in Vertical flow CW

2. Design and construction of Constructed wetlands

Landscape integration



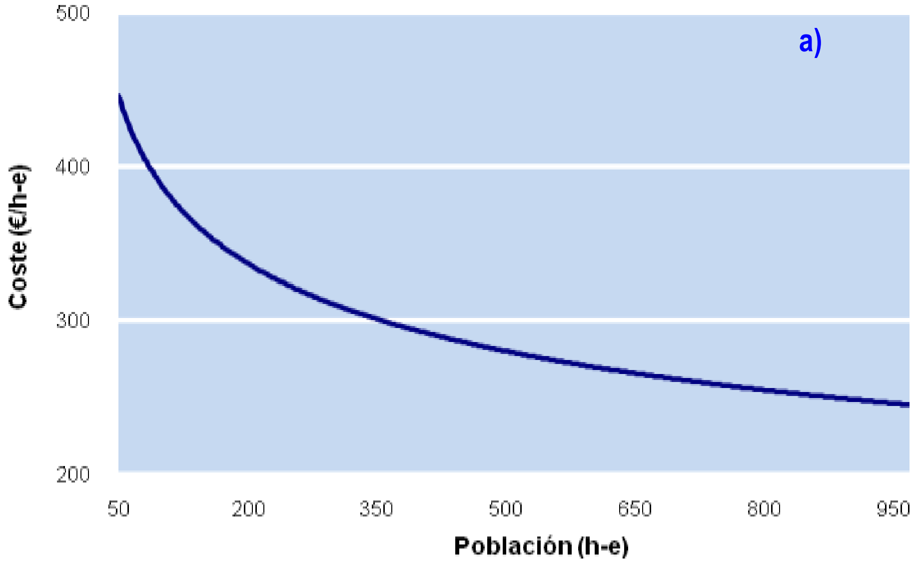


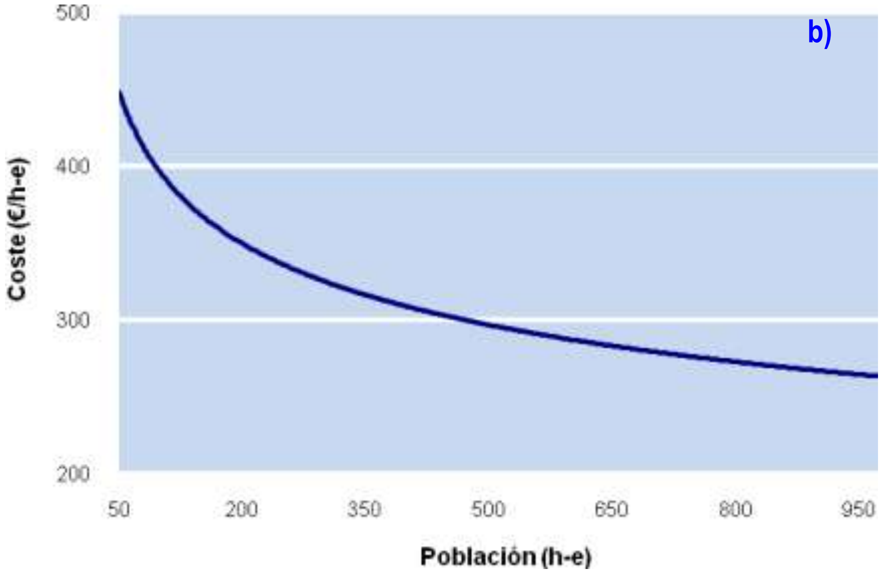

2. Design and construction of Constructed wetlands

Landscape integration

2. Design and construction of Constructed wetlands

Costs





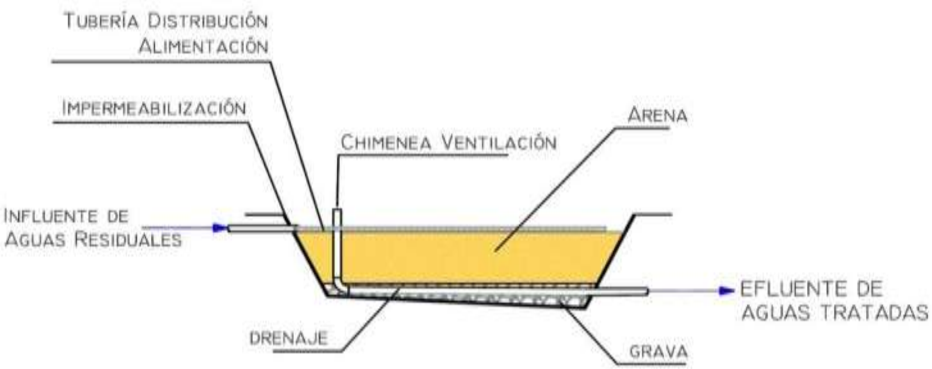
Implementation costs per p.e. for Subsurface CW (a) *Vertical* and (b) *Horizontal*

Table of contents

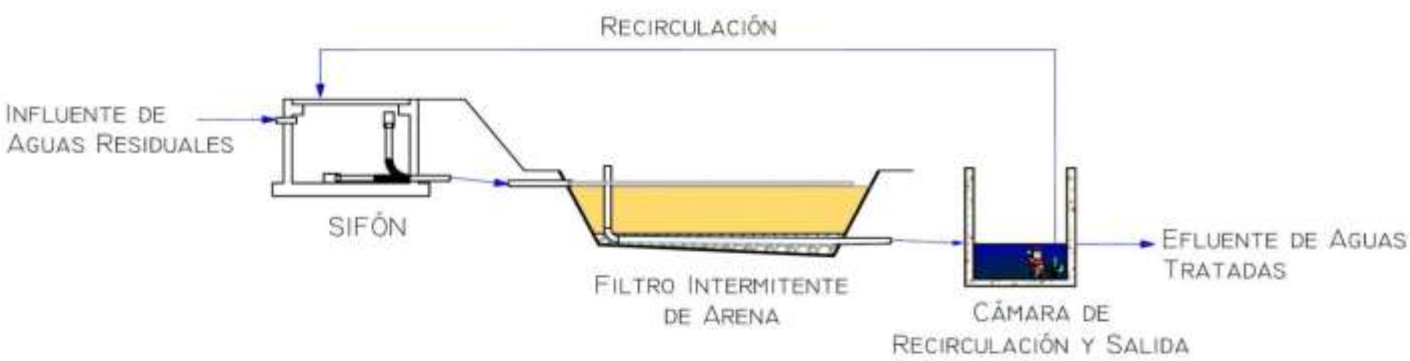
3. Design and construction of Intermittent Sand Filters

ISF typologies

ISF without recirculation



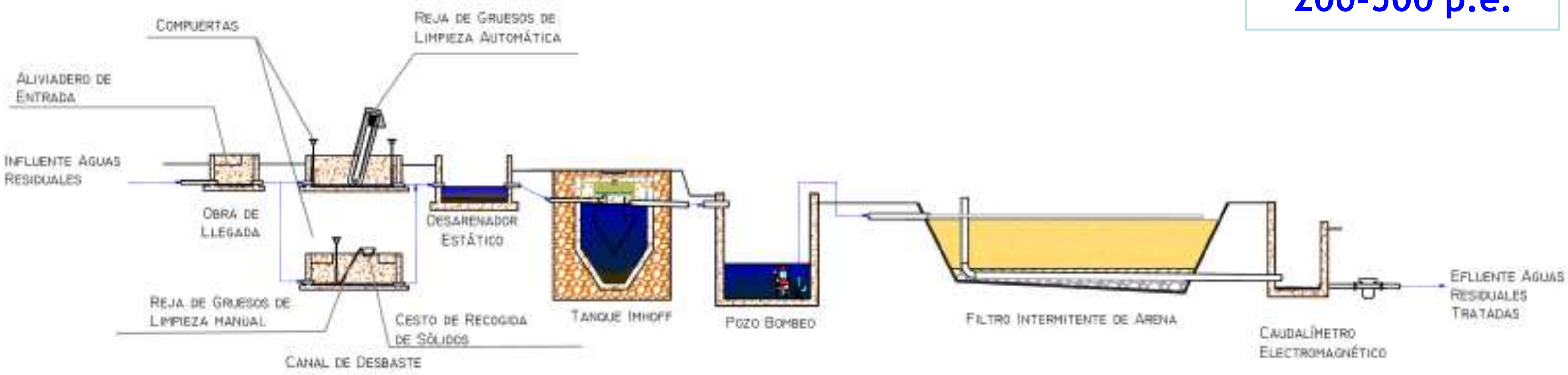
ISF with recirculation



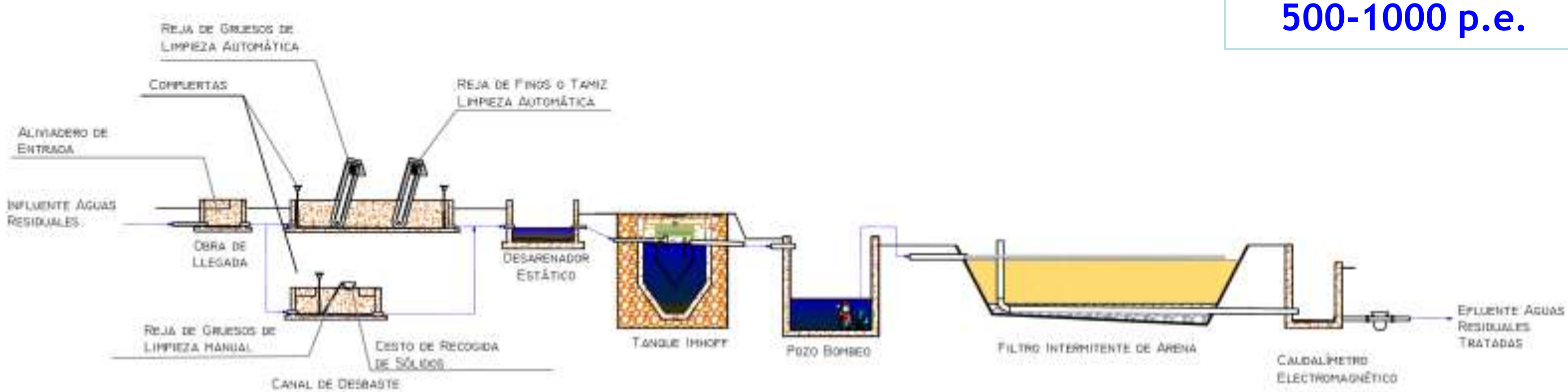
3. Design and construction of Intermittent Sand Filters

ISF without recir.: flow diagrams

200-500 p.e.



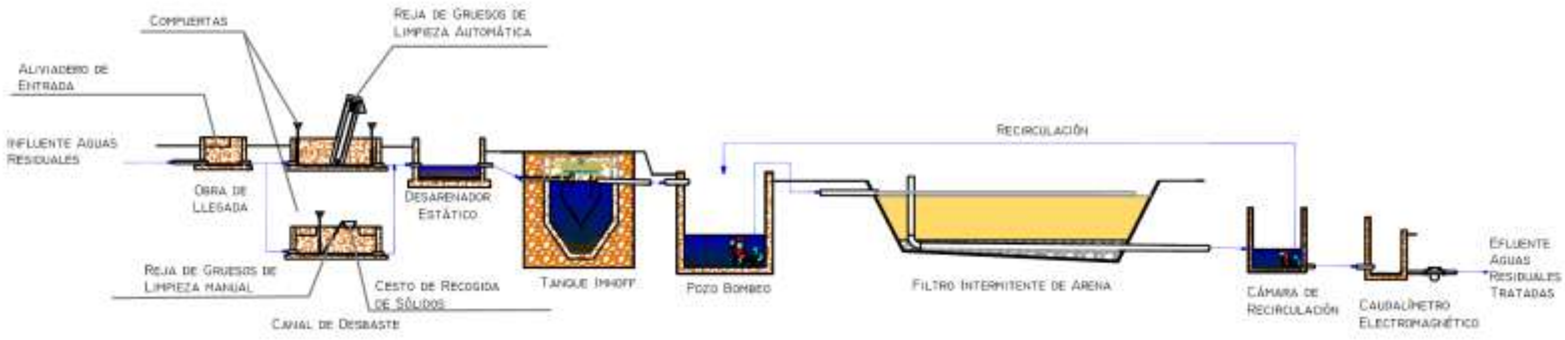
500-1000 p.e.



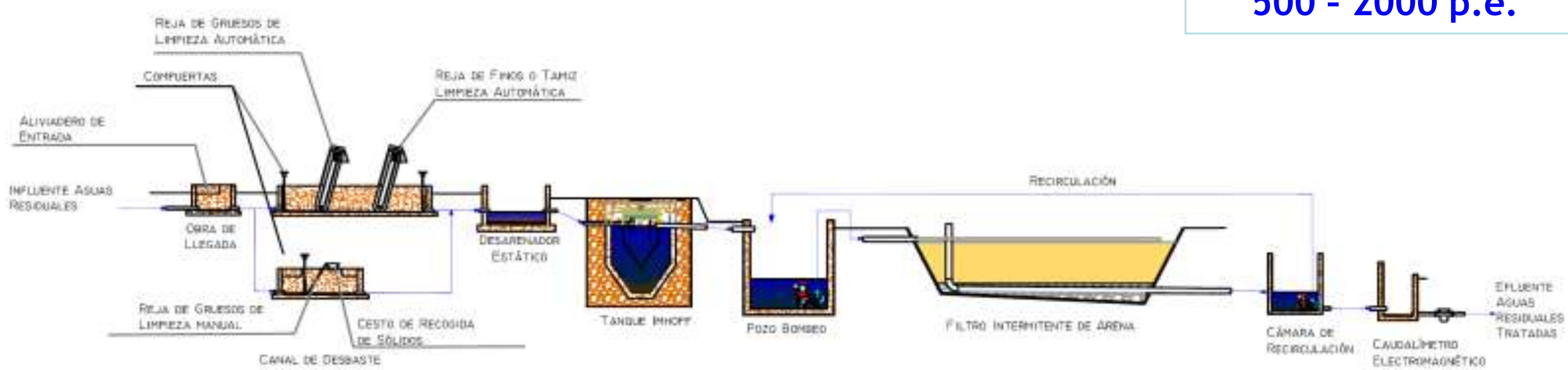
3. Design and construction of Intermittent Sand Filters

ISF with recir.: flow diagrams

200 - 500 p.e.

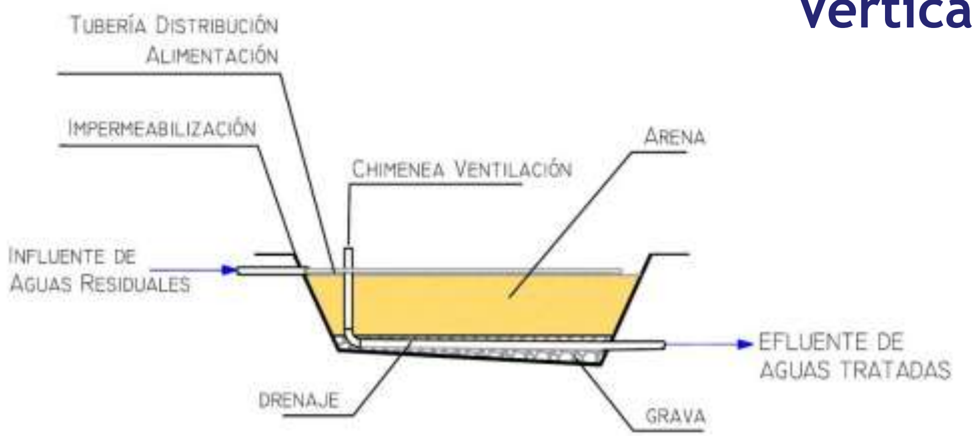


500 - 2000 p.e.

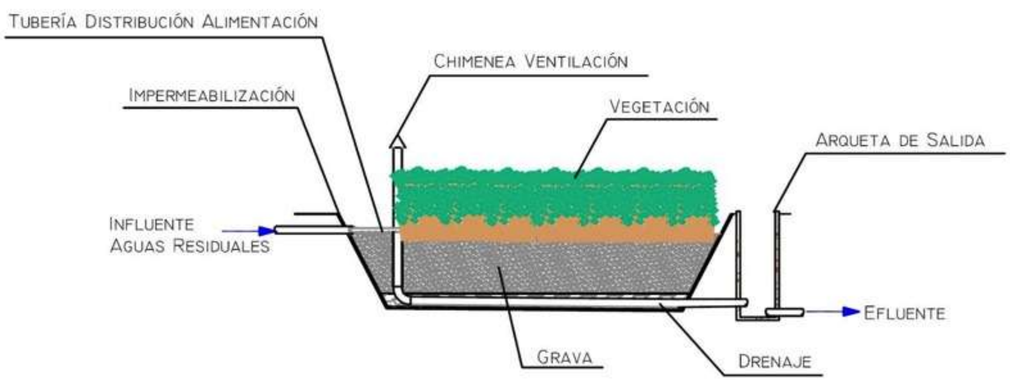


3. Design and construction of Intermittent Sand Filters

Similarities between ISF and Vertical Flow CW



ISF



Vertical flow CW

3. Design and construction of Intermittent Sand Filters

ISF design criteria

Design criteria for Intermittent Sand Filters (EPA)

Parameters	Intermittent Sand Filter without recirculation	Intermittent Sand Filter with recirculation
Organic load (g $BOD_5/m^2.d$)	24[1]	48 – 72
Hydraulic load ($l/m^2.d$)	40 - 80	120 – 200
Dosage frequency (number/d)	12 - 24[2]	48
Recirculation ratio (Q_r/Q_0)	-	3 – 5

[1] For sand filters with 1 mm size sand and a dosage pattern of 12 times per day.

[2] The number of dosages increases with the BOD of the effluent of the primary tank. It is recommended to augment the dosage to 24 times per day for sewage water with a BOD_5 upper tan 200 mg/l.

3. Design and construction of Intermittent Sand Filters

ISF design criteria

Design criteria for Intermittent Sand Filters (EPA)

Parameters	Intermittent Sand Filter without recirculation	Intermittent Sand Filter with recirculation
Width of the filtering bed	0.6-0.9	0.6-1.1
Capacity of the dosage tank (times x daily flow rate)	40 - 80	120 – 200
Filtering media	Sand with an effective size of 0.25-1.00 mm and a uniformity coefficient < 4	Gravel with an effective size of 3.0-20.0 mm and a uniformity coefficient < 2.5

The filtering media must be washed and the percentage of fine particles < 0.074 mm must not exceed 3% of the total mass.

3. Design and construction of Intermittent Sand Filters

ISF constructive recommendations

- ✓ The intermittent Sand Filters are normally excavated on the soil.
- ✓ The length and width of the ISF are similar
- ✓ The bottom of the filter have a 0.1% slope to the exit.
- ✓ The walls have 45º of inclination.
- ✓ The confinement must be impermeable.

3. Design and construction of Intermittent Sand Filters

ISF pics

3. Design and construction of Intermittent Sand Filters

ISF for water reclamation





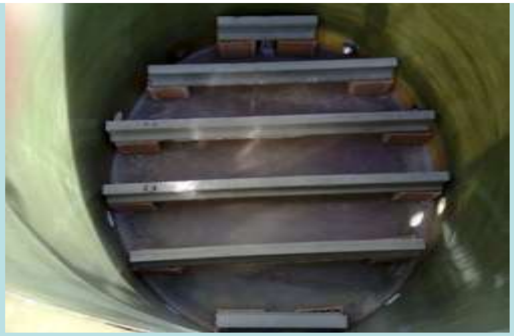




3. Design and construction of Intermittent Sand Filters

ISF for water reclamation







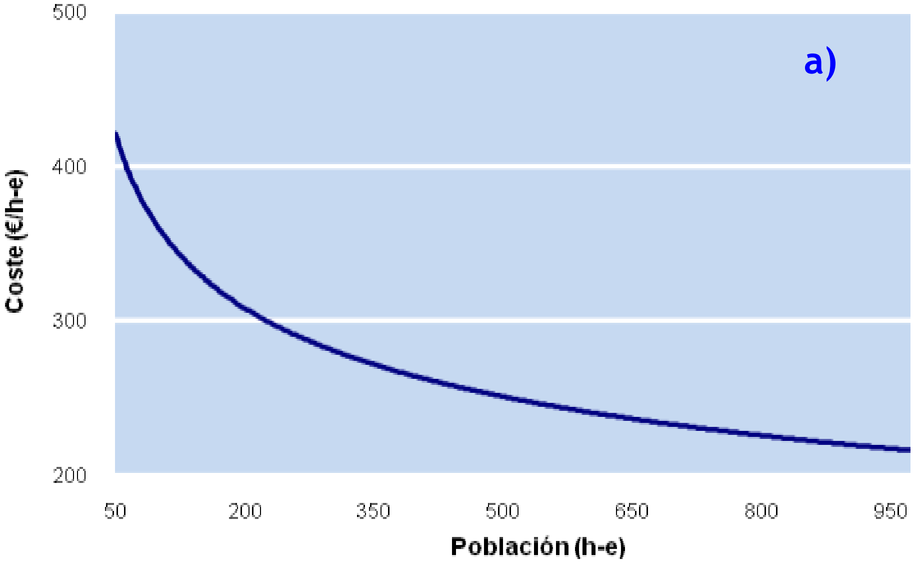


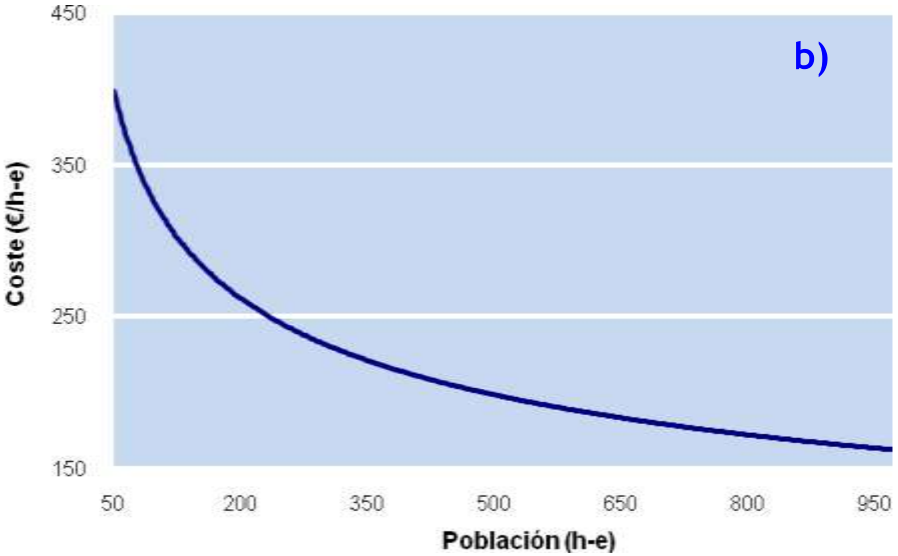
3. Design and construction of Intermittent Sand Filters

ISF for water reclamation

3. Design and construction of Intermittent Sand Filters

Costs



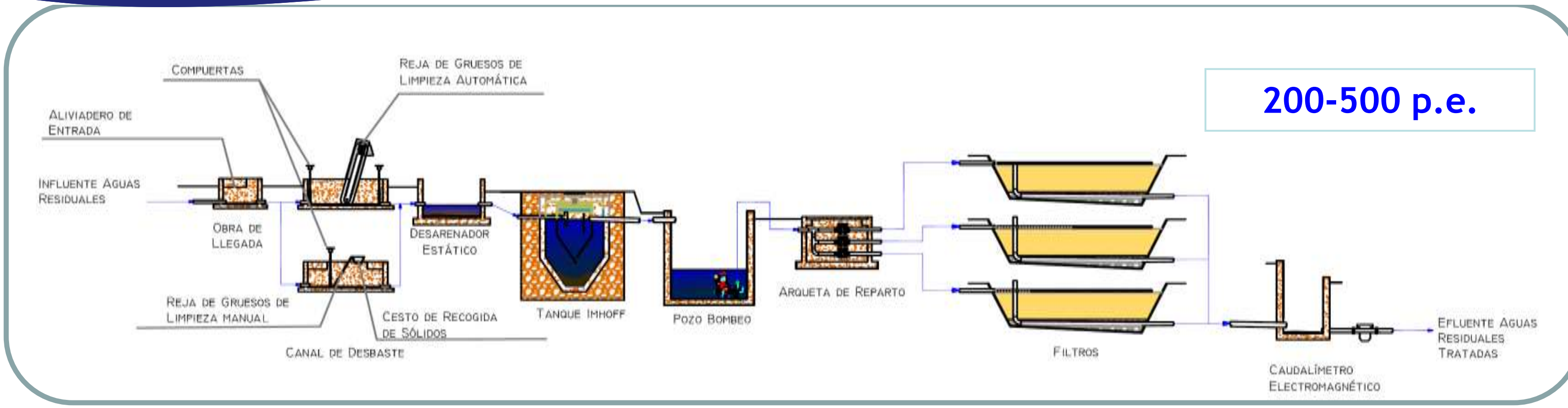


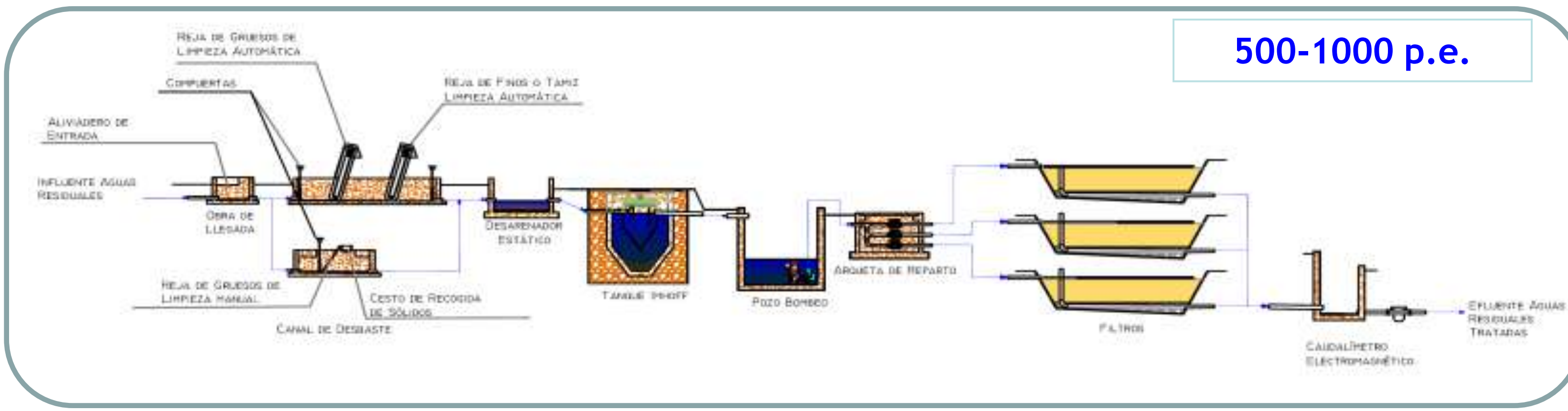
Implementation costs per p.e. for Intermittent Sand filters a) without recirculation and b) with recirculation

Table of contents

4. Design and construction of Infiltration-percolation systems

Infiltration-Percolation: flow diagrams



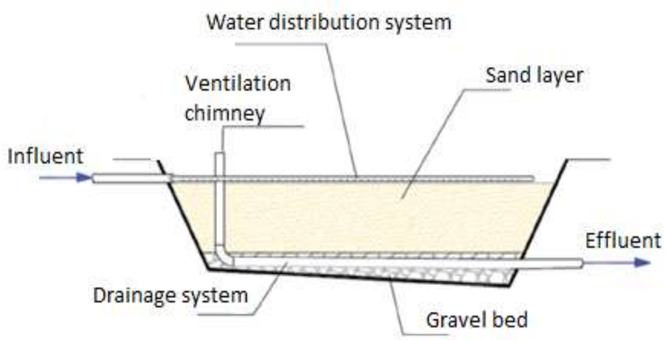


Usually, the WWTP based on I-P systems have 3 filtering units which work 3-4 days each one and rest during 6-8 days.

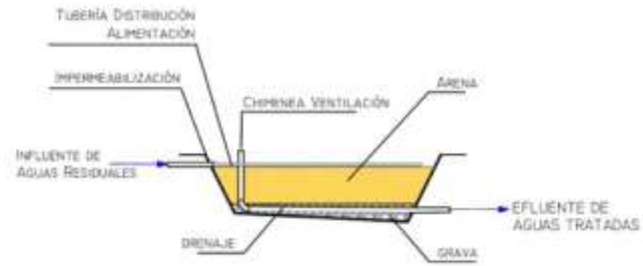
In very small agglomerations (< 100 p.e.) 2 filtering units can be operated in parallel, working/resting during 3-4 days each one.

4. Design and construction of Infiltration-percolation systems

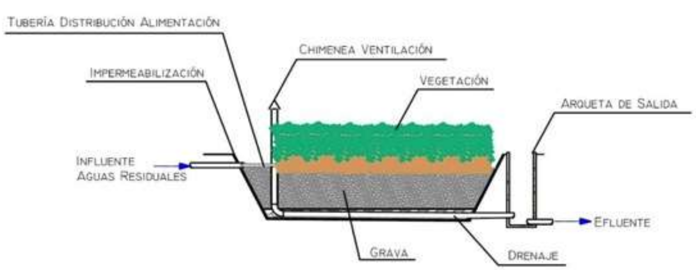
Similarities between modified I-P, ISF and Vertical flow CW



Modified I-P



ISF



Vertical flow CW

4. Design and construction of Infiltration-percolation systems

I-P design criteria

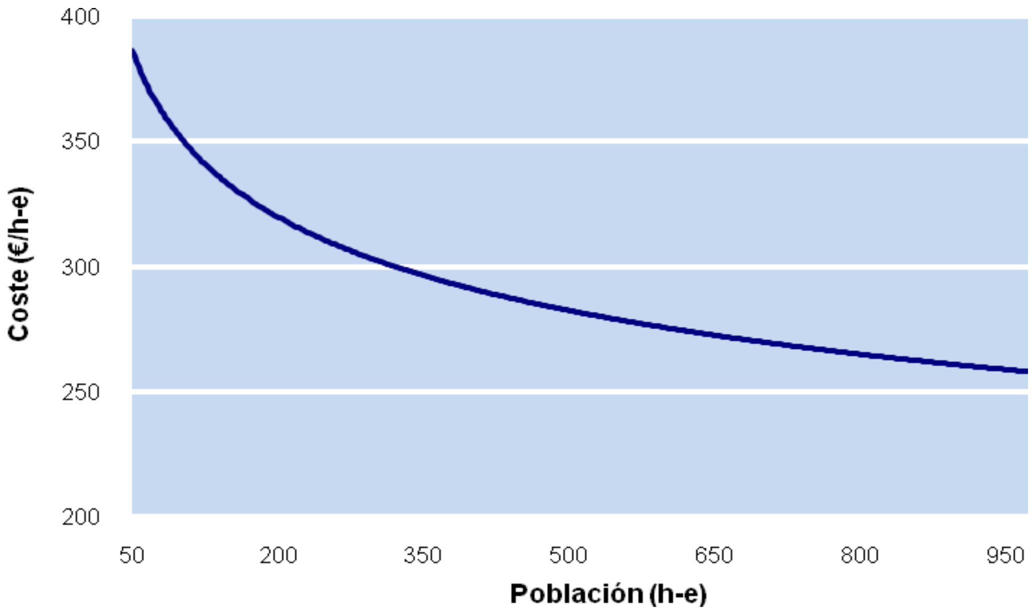
Design criteria for modified Infiltration-Percolation systems

Parameters	Infiltration-Percolation
Organic load (g $BOD_5/m^2.d$)	40
Number of filtering units	Normally 2, 3-4 days working and 6-8 days in resting period.
Dosage frequency (nº/d)	3 – 6
Width of the filtering bed	0.8 m 1.5 m (for disinfection)
Filtering media	Siliceous sand, d_{10} = 0.25 – 0.40 mm, uniformity coefficient (C_u)= 3 - 6

The filtering media must be washed and the percentage of fine particles < 0.074 mm must not exceed 2.5% of the total mass.

4. Design and construction of Infiltration-percolation systems

Costs



Implementation costs per p.e. for Infiltration-Percolation systems

Table of contents

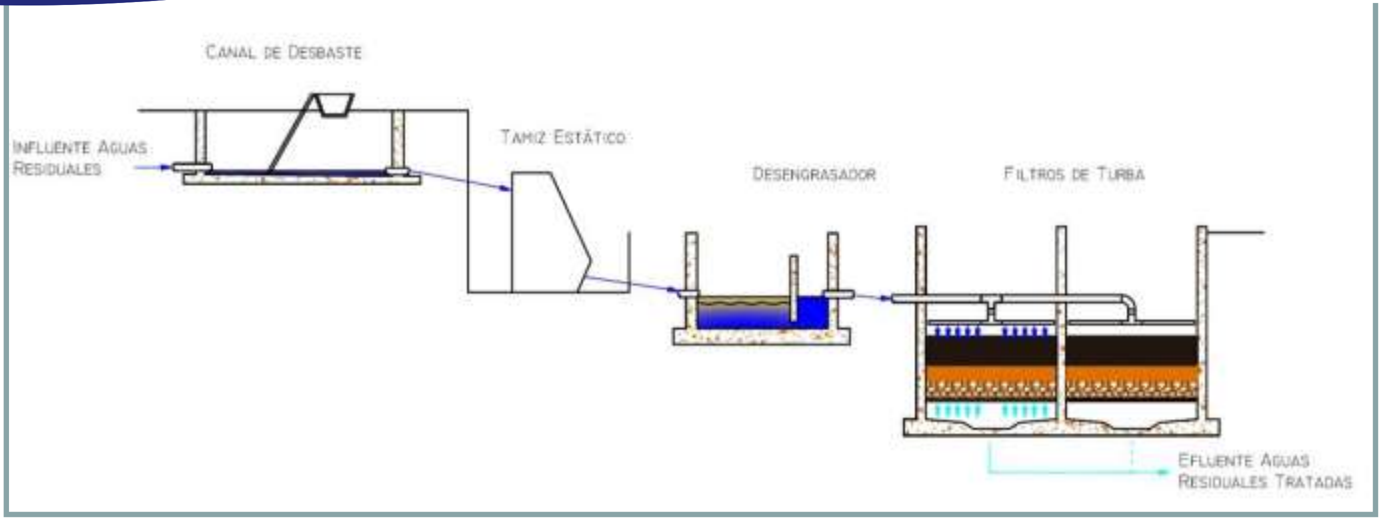
5. Design and construction of Peat Filters

Peat's requirements

pH (extract 1:5)	6 - 8
Conductivity (extract 1:5) (dS/cm)	< 5
Humidity (%)	50 - 60
Ashes (%)	40 - 50
Organic matter by calcination (%)	50 - 60
Total Humic Extract (%)	20 - 30
Humic acids (%)	10 - 20
C.I.C. (meq/100 g)	> 125
C/N ratio	20 - 25
Kjeldhal Nitrogen (% N)	1.2 - 1.5
Iron (ppm)	< 9000
Hydraulic conductivity ($l/m^2.h$)	25

5. Design and construction of Peat Filters

Peat filter: classical flow diagram



5. Design and construction of Peat Filters

Peat filter classical design

Design criteria for the classical peat filters flow diagram

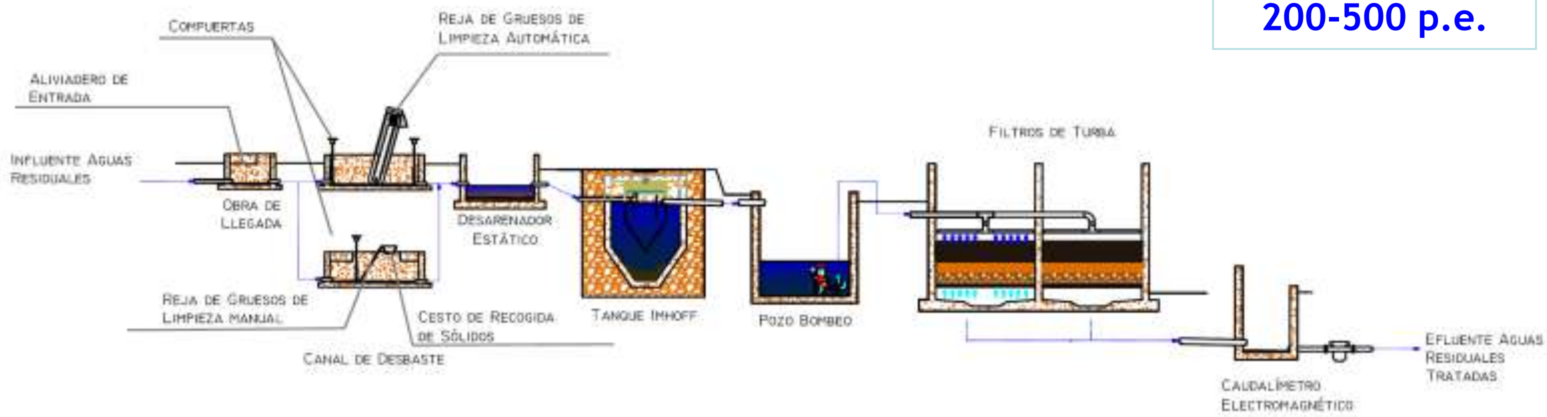
Parameter	Value
Hydraulic load ($l/m^2.d$)	600
Organic load (g $BOD_5/m^2.d$)	≤ 300
Solids load (g $SS/m^2.d$)	≤ 240
Ratio total surface/ active surface	2:1

According to this design, 1 equivalent inhabitant only requires 0.2 m^2 of active peat and 0.4 m^2 of total surface

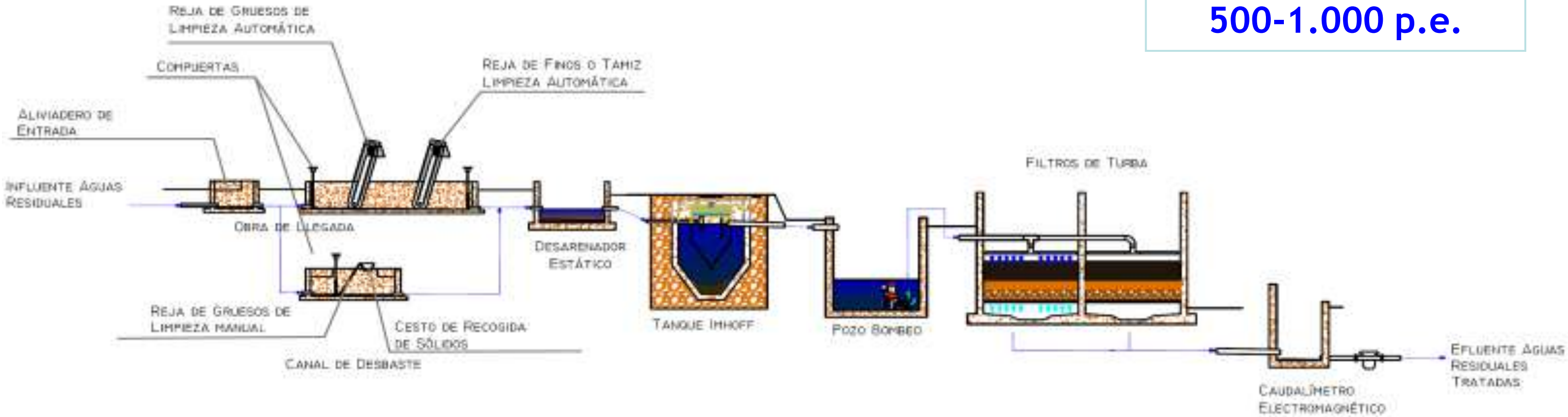
5. Design and construction of Peat Filters

Peat filter: new flow diagrams

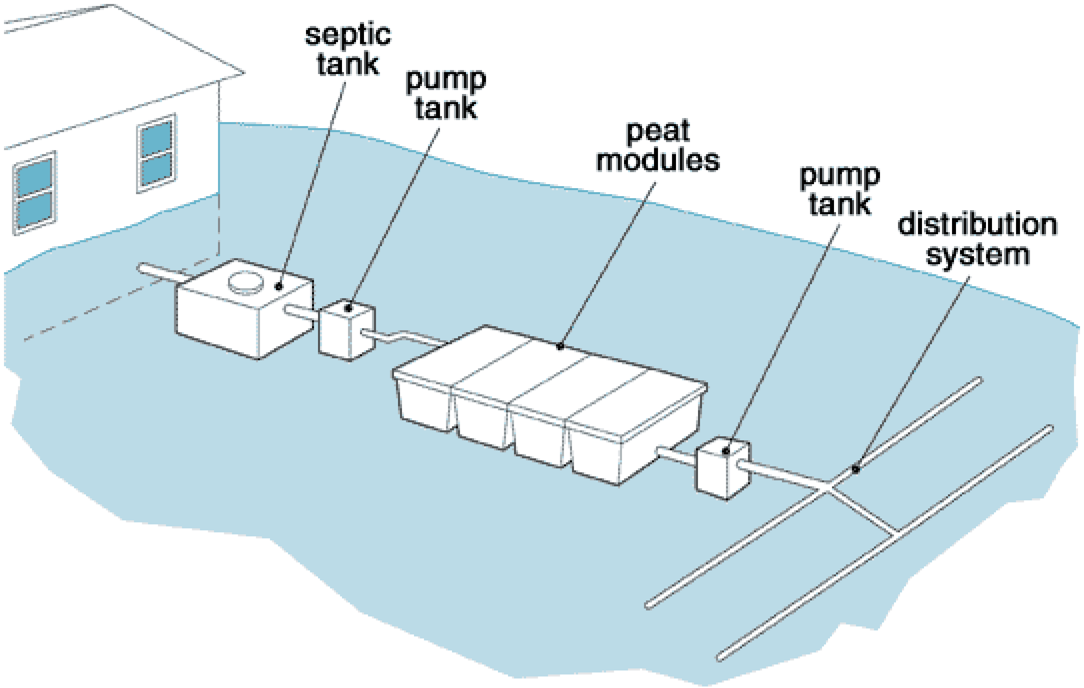
200-500 p.e.

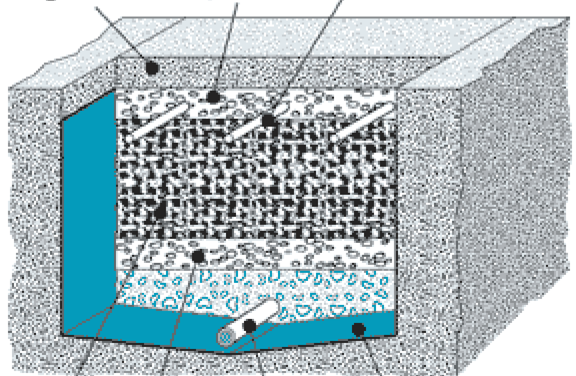


500-1.000 p.e.



5. Design and construction of Peat Filters

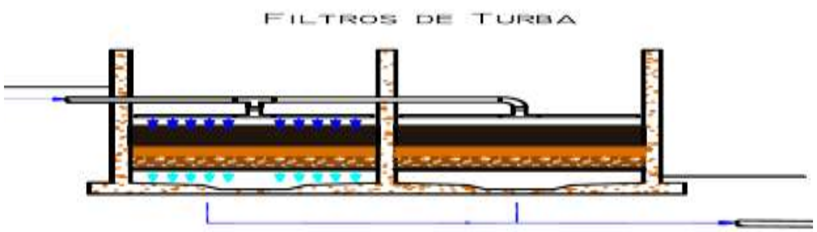




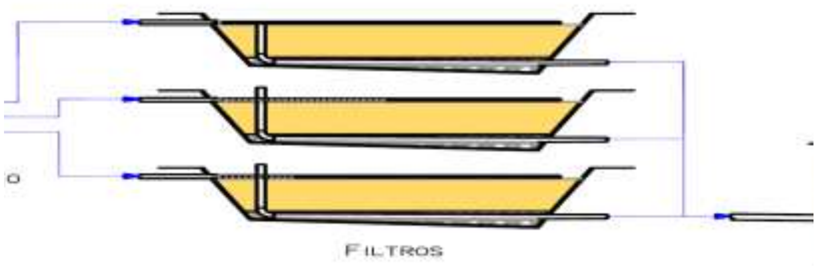
http://www.extension.umn.edu/distribution/naturalresources/dd7669.html

5. Design and construction of Peat Filters

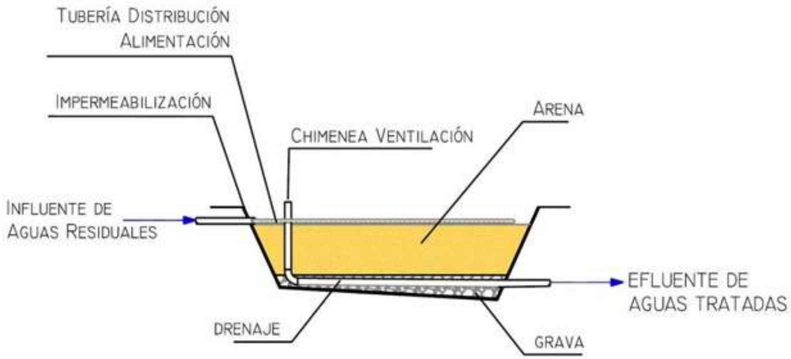
Similarities between Peat filters, Modified I-P, ISF and Vertical flow CW



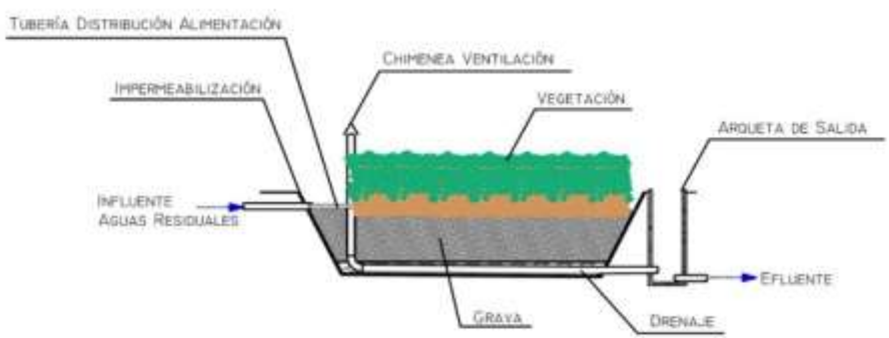
Peat Filter



Modified Infiltration-Percolation



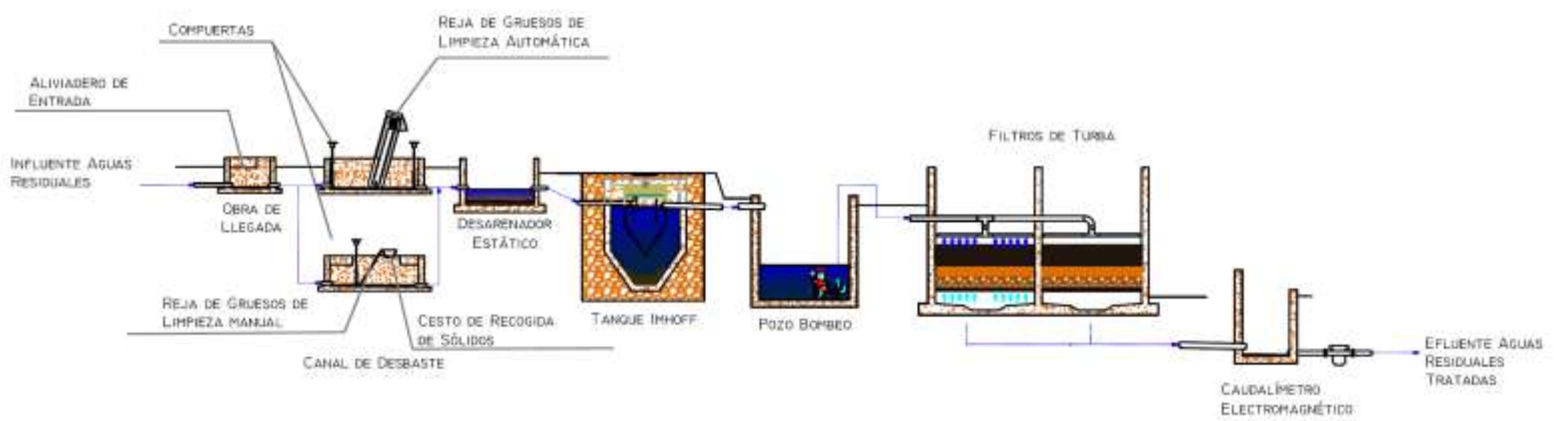
Intermittent Sand Filter



Vertical Flow CW

5. Design and construction of Peat Filters

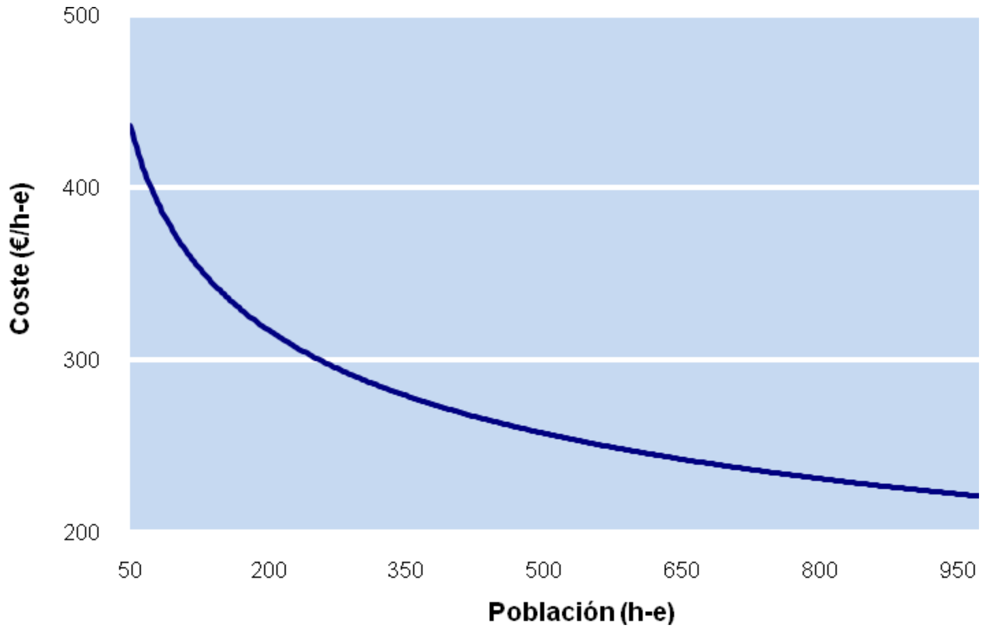
Peat filter: new design criteria



The design organic load is around 24 g $BOD_5/m^2.d$, which requires a surface area of 1.9 m^2 / P.E. to install the filters, assuming a 25% performance rate during the pre-treatment phase.

5. Design and construction of Peat Filters

Costs

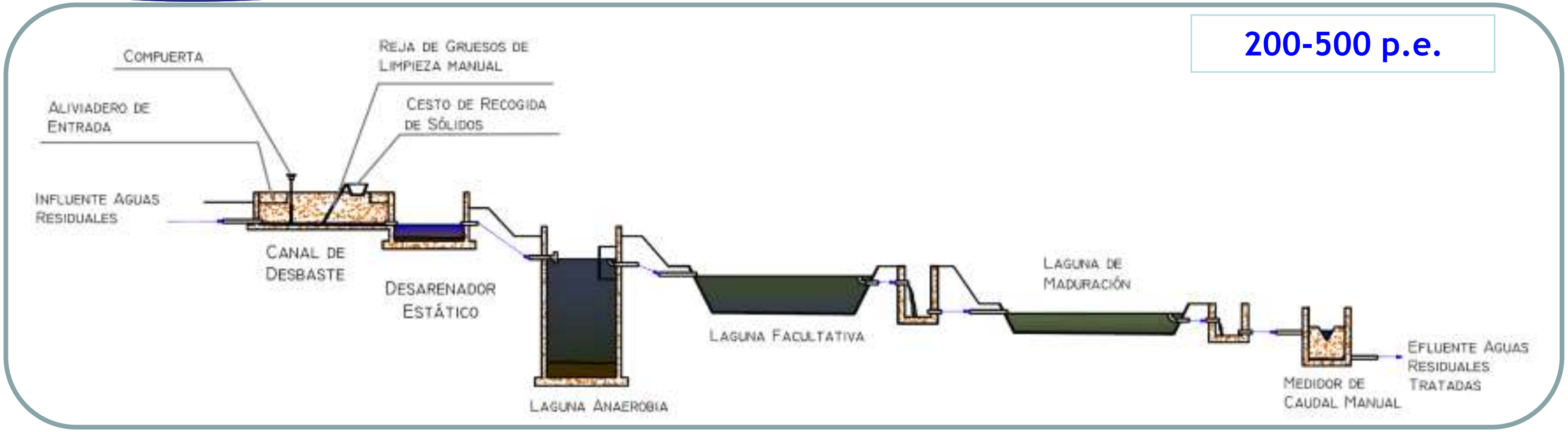


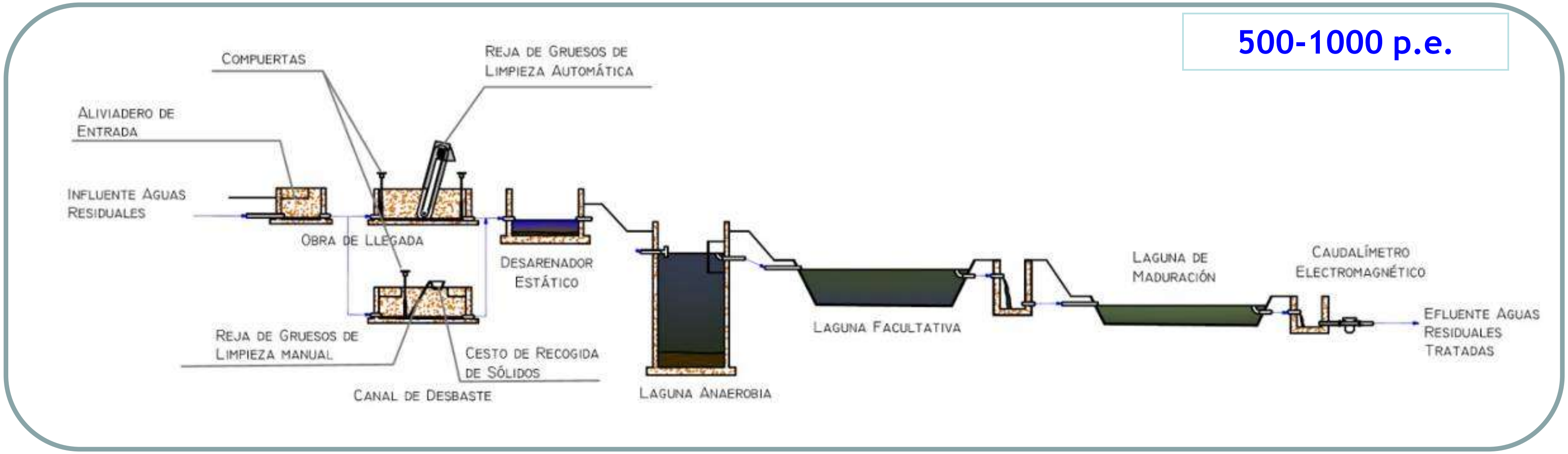
Implementation costs per p.e. for Peat Filters

Table of contents

6. Design and construction of Lagooning

Lagooning: flow diagrams





6. Design and construction of Lagooning

Anaerobic pond: design

Empirical design based on both the volumetric load and the retention time

Volumetric load expressed as:

$$C_v = C_{(e)} \cdot Q_{md} / V$$

where:

- C_v: volumetric load (g BOD_5/m^3.d)
- $C_{(e)}$: influent BOD_5 (mg/l = g/m^3)
- Q_{md}: daily average flow rate (m^3/d)
- V: pond capacity (m^3)

$$V = C_{(e)} \cdot Q_{md} / C_v$$

The volumetric load depends on the temperature (normally, the average temperature of the coldest month)

Temperature (°C)	Volumetric load (C_v) (g/m^3.d)	BOD_5 removal (%)
< 10	100	40
10 – 20	20T-100	2T + 20
20 – 25	10T + 100	2T + 20

6. Design and construction of Lagooning

Anaerobic pond: design

Hydraulic retention time:

$$\theta = V / Q_{md}$$

where:

θ: Hydraulic retention time (d)

θ must be $\geq$ *2 days*. If $\theta < 2$ days, θ is fixed in 2 days and the capacity of the anaerobic pond is then recalculated.

Dimensioning criteria:

- ✓ Height= *3-5 m*
- ✓ Internal slope*(normally 2:1, horizontal : vertical)*

6. Design and construction of Lagooning

Facultative pond: design

The maximum *Organic load* (kg BOD_5/ha.d) that can be applied to the facultative pond before its conversion to anaerobic conditions is expressed as follows:

$$\lambda_s = 350\ (1.107 - 0.002\ T)^{T-25} \quad \text{(Mara)}$$

λ_s = superficial organic load (kg BOD_5/ha.d).

T = temperature (°C) [the average temperature of the coldest month].

- ✓ *Example: 20ºC ▸ 253 kg BOD_5/ha·d*
- ✓ For T ≈ 10°C, the organic load must be ≤ *100 kg BOD_5/ha·d*.
- ✓ If the T< 8 °C the organic load must be ≤ *80 kg BOD_5/ha·d*.

Knowing the inlet organic load in the facultative pond and considering the limit above-mentioned, the surface required for the facultative pond is calculated.

Establishing the depth of the water column (1.5-2.0 m), the clearance (≈0.5 m), the internal slopes (usually, 3:1, horizontal:vertical), and the geometric shape of the pond, the total and effective capacity is calculated.

6. Design and construction of Lagooning

Maturation pond: design

Hydraulic retention time (θ, days)

$$\theta = V / Q_{md}$$

For guarantying an effective pathogens' removal a minimum θ = 5 days is recommended if only one maturation pond is installed, and θ = 3 days if two maturation ponds are working in series.

Knowing the flow rate and the required θ, the capacity of the maturation pond is calculated. ($V = \theta \cdot Q_{md}$).

Establishing the depth of the water column (0.8-1.0 m), the internal slopes (usually, 3:1, horizontal:vertical), and the geometric shape of the pond, the required surface is calculated.

For avoiding organic overloads, the superficial organic load on the maturation pond must not exceed 75% of the organic load at the facultative pond. If this requirement is not meet both the surface and capacity of the maturation pond must be recalculated.

6. Design and construction of Lagooning

Constructive issues






6. Design and construction of Lagooning

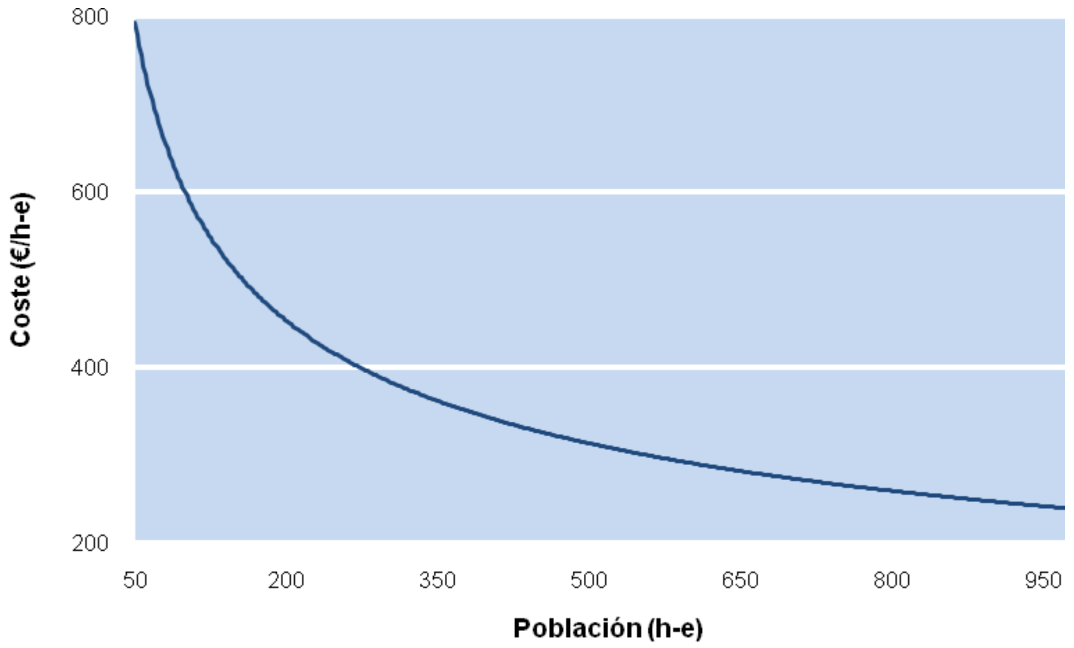
Constructive issues






6. Design and construction of Lagooning

Costs

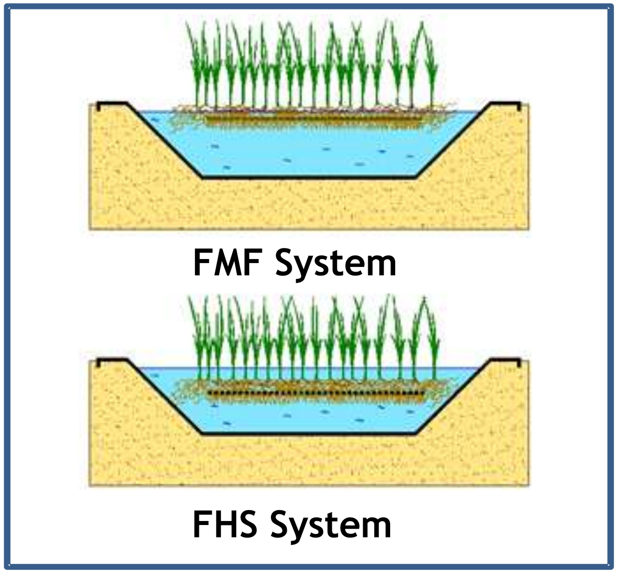


Implementation costs per p.e. for Lagooning system

Table of contents

7. Design and construction of other soft technologies

Macrophytes on flotation



Source: Hidrolution S. L.

Fabara WWTP (Zaragoza) (FHS)

WWTP Los Cortijos (Ciudad Real) (FMF)

7. Design and construction of other soft technologies

Macrophytes on flotation

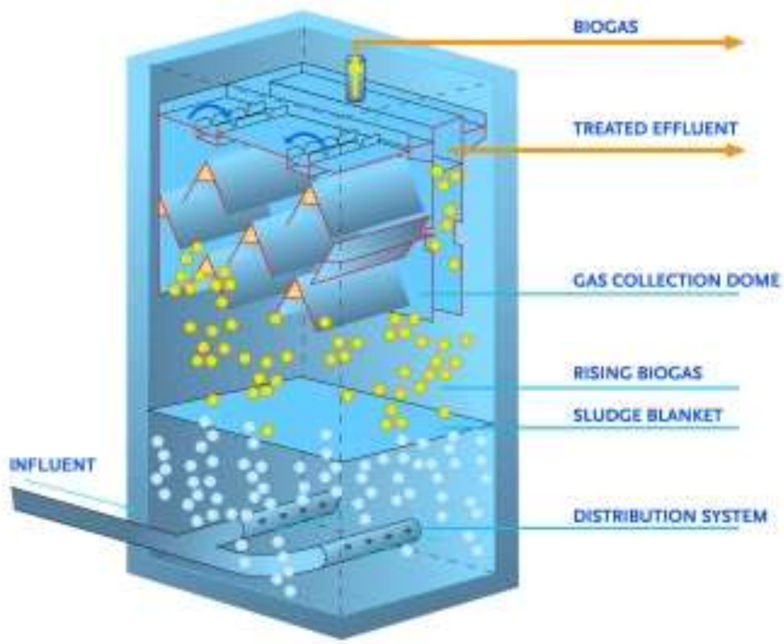
Design parameters: FMF and FHS systems

Parameter	FMF system	FHS system
Required planted surface (m^2/pe)	1 - 3	1.5 – 2.5
Hydraulic retention time (d)	7.5 – 10	> 5
Location of macrophytes	Ponds	Channels with 2.5 - 4 m of width
Water depth(m)	0.5 - 5	> 0.5
Vegetation	Emergent macrophytes	Fundamentalmente eneas o esparganios
Plantation density (plants/m^2)	10.8 – 40.5	10
Maintenance	Phyitosanitary treatment	Segado 2 o 3 veces al año
Period of time required for the starting up (gaining high performance)	1 vegetative period	1 year
Pre-treatment	Screening + grit removal+ sieving + grease removal	Screening + Septic tank/Imhoff tank

Source: Hidrolution (Sistema FMF). Universidad Politécnica de Madrid (Sistema FHS)

7. Design and construction of other soft technologies

UASB anaerobic reactors



- ✓ Employed both for primary and secondary treatment.
- ✓ UASB reactors can remove up to 75-85% of incoming COD and 70% of suspended solids contained in the sewage.

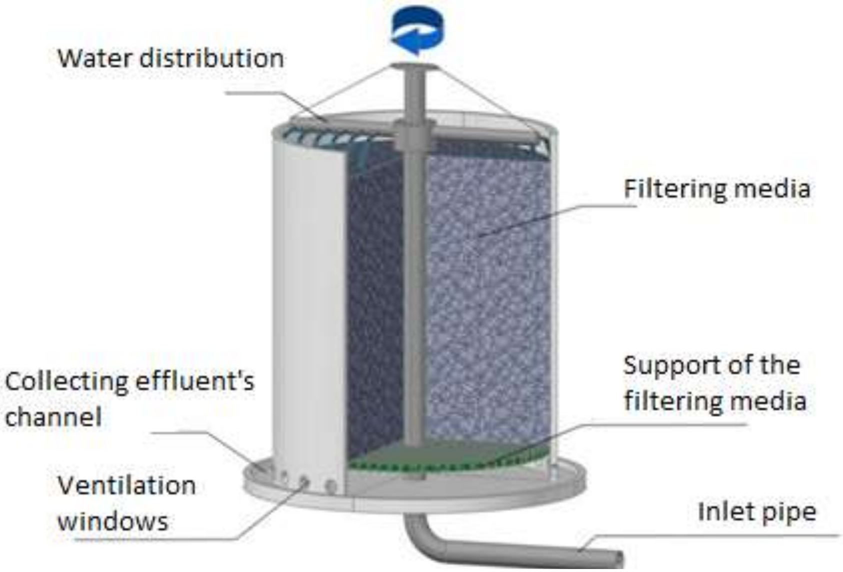
7. Design and construction of other soft technologies

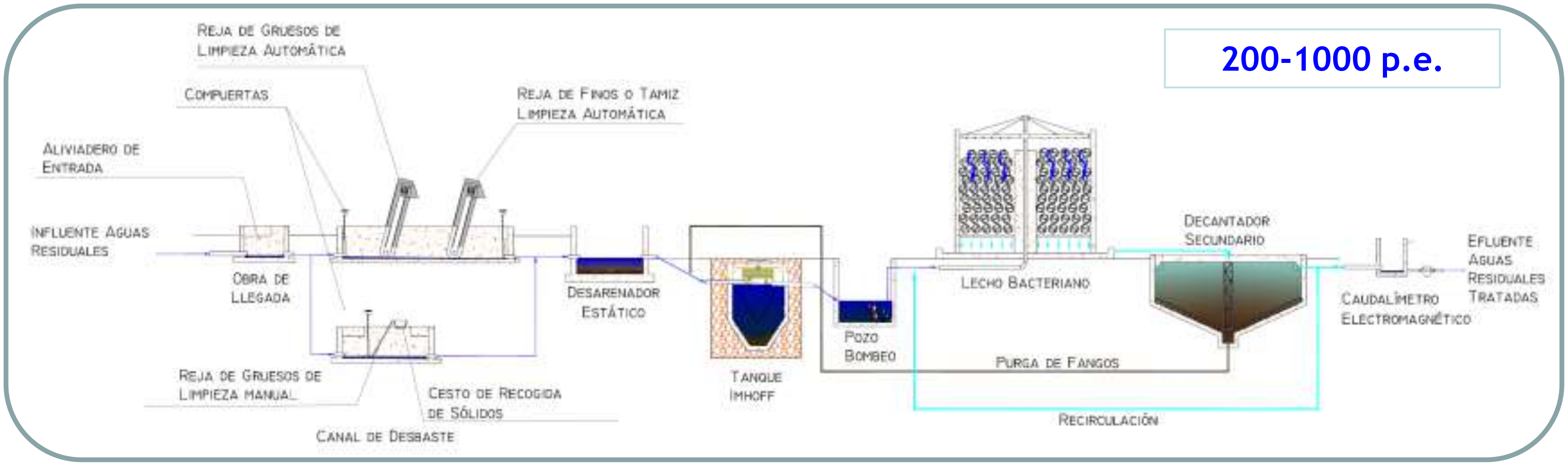
UASB anaerobic reactors

- ✓ In order to maintain the sludge suspended, the speed of the upward flow must be between 0.6 and 0.9 m/h.
- ✓ The standard operation parameters are as follows:
  - Organic loading rate (kg COD/m3.d) = 5-30
  - Hydraulic residence time (d) = 2-0.2
  - Start-up time (d) = 30-90
  - Organic load of the influent (mg COD/l) = 300-80000
  - Superficial velocity (m/h), us
  - Granular sludge, us= 1-3 m/h
  - Flocculent sludge, us= 0.5-0.75 m/h
  - Height (m) = 5-8

7. Design and construction of other soft technologies

Trickling filters





200-1000 p.e.

7. Design and construction of other soft technologies

Trickling filters

Recommendations for the design of low load Trickling Filters

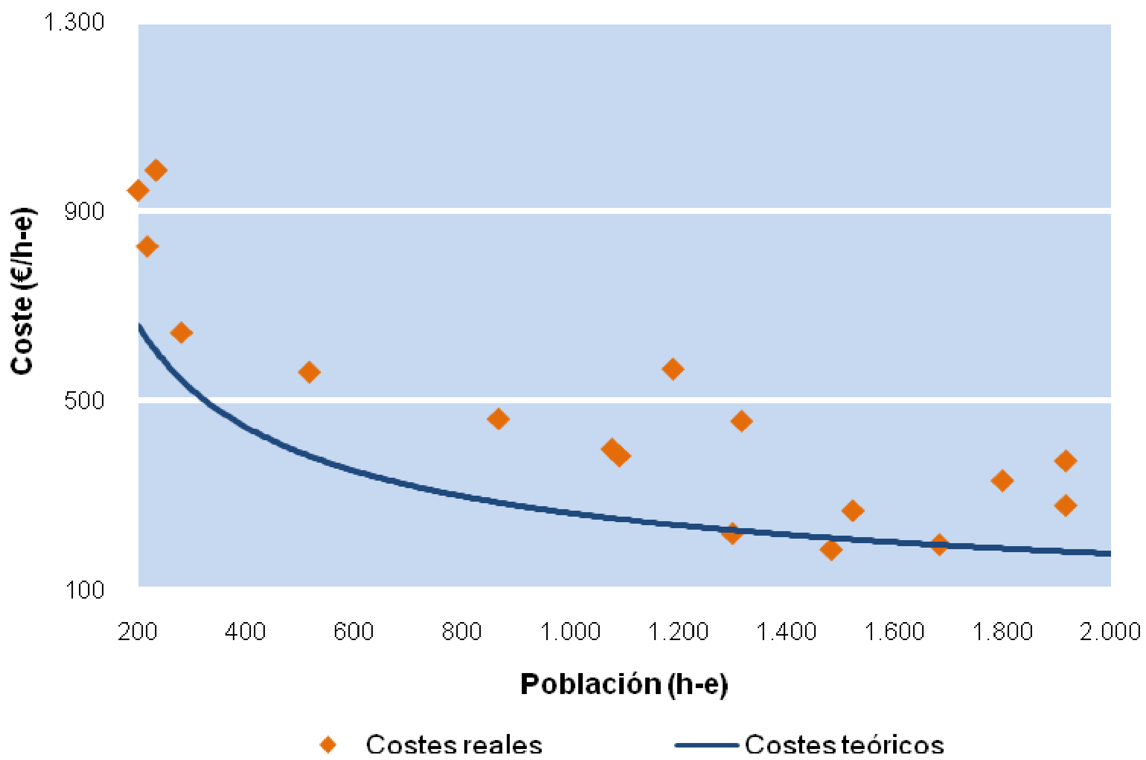
Parameter	Recommended value
Organic load (kg $BOD_5/m^3.d$)	0.2 – 0.4
Maximum hydraulic load ($m^3/m^2 \cdot h$)*	>0.4 (filled with stones) >0.8 (plastic fillings)
Filling's height (m)	2 – 3 m (filled with stones) 4 – 5 m (plastic fillings)
Recirculation (Q_r/Q)**	1-2

*** For the maximum flow rate (Qmax)**

**** For the hourly medium flow rate (Qm,h)**

7. Design and construction of other soft technologies

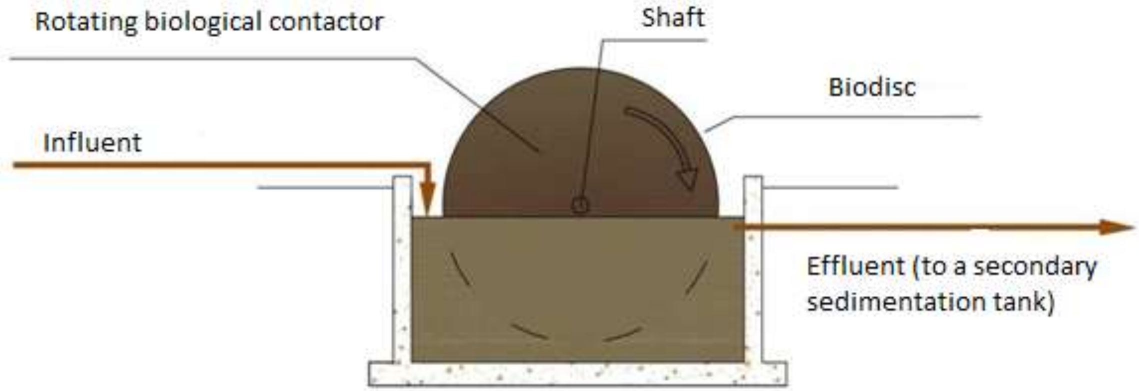
Trickling filters

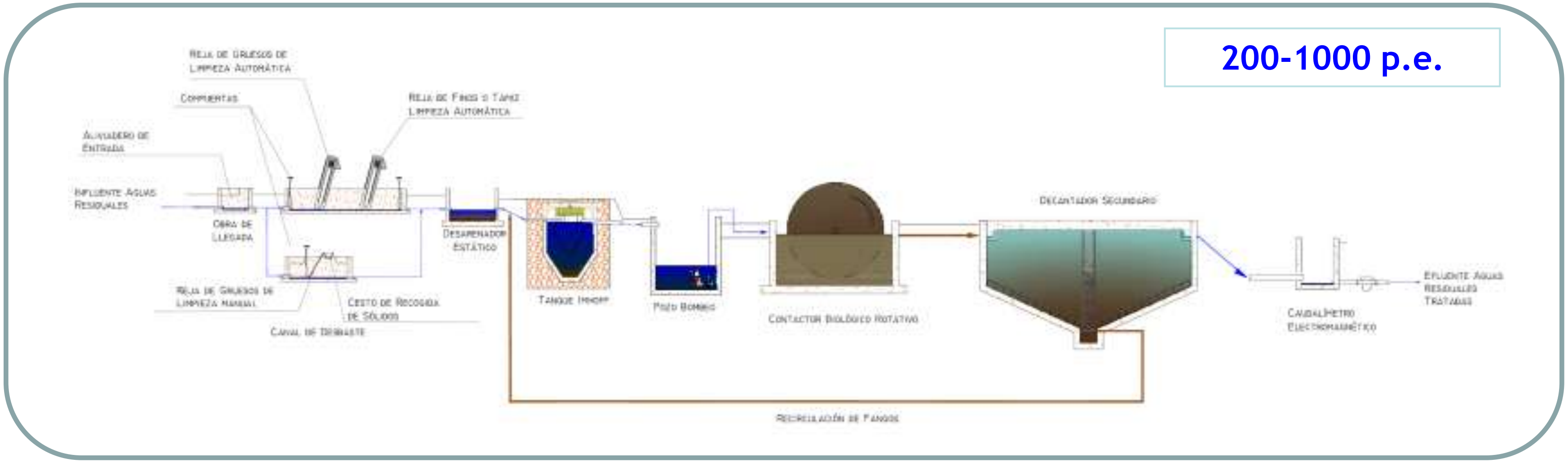


Implementation costs per p.e. for Trickling Filters

7. Design and construction of other soft technologies

Rotating Biological Contactors





7. Design and construction of other soft technologies

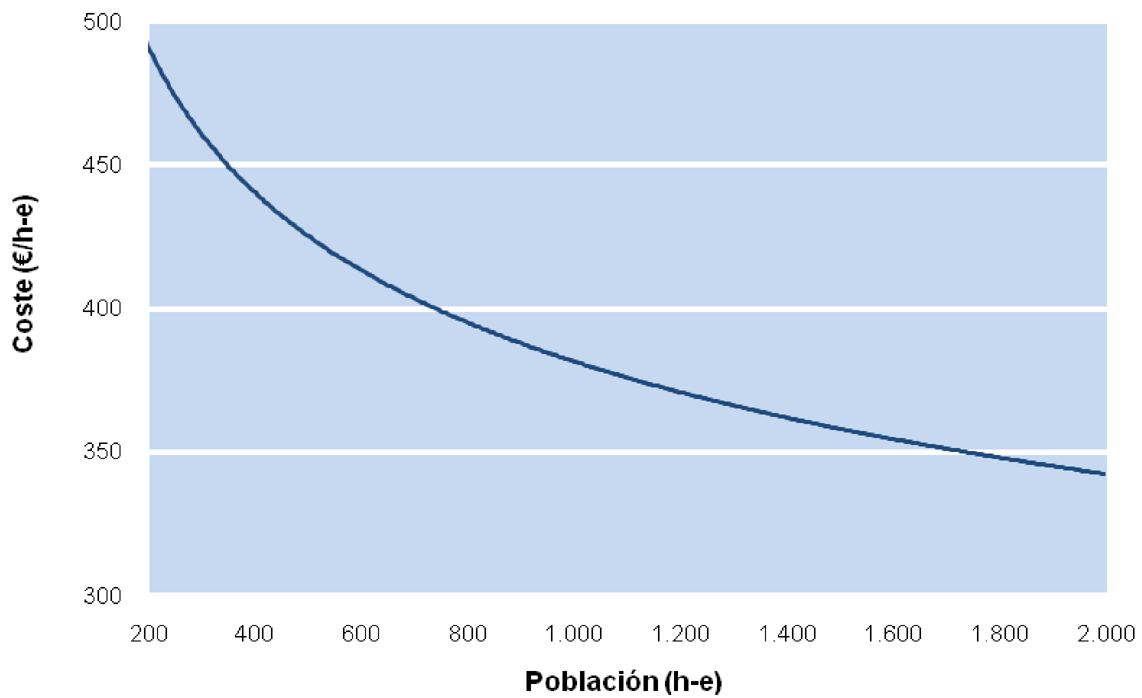
Rotating Biological Contactors

Design criteria for RBC

Parameter	Value
Organic load in the first stage	< 40 g BOD_5 /m^2·d
Hydraulic load	
- BOD_5 removal	≤ 0.15 m^3/m^2.d
- Nitrification	≤ 0.07 m^3/m^2.d
Specific surface of the RBC	
- BOD_5 removal	110 m^2/m^3
- Nitrification	200 m^2/m^3

7. Design and construction of other soft technologies

Rotating Biological Contactors



Implementation costs per p.e. for RBC

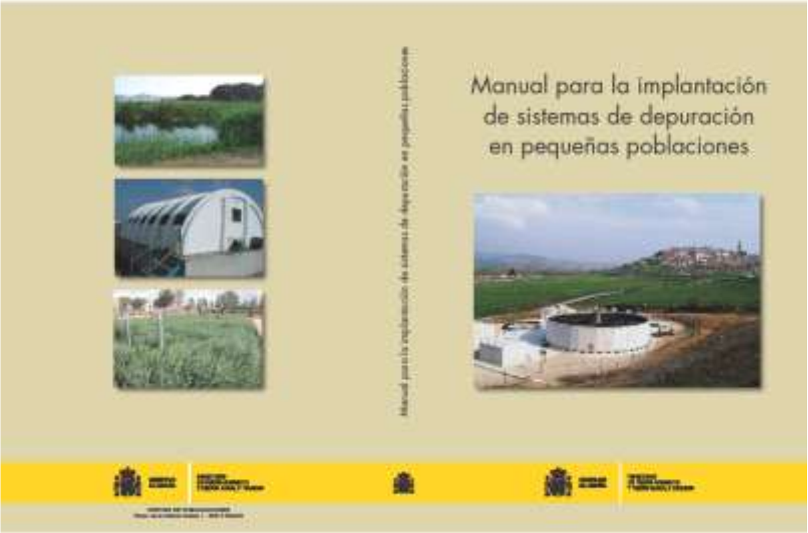
Main Reference

MINISTERIO
DE FOMENTO
MINISTERIO
DE MEDIO AMBIENTE,
Y MEDIO RURAL Y
MARINO

CEDEX

CENTRO DE ESTUDIOS Y
EXPERIMENTACIÓN DE OBRAS
PÚBLICAS

centa



"Guidelines for the implementation of wastewater treatment systems in small populations". Ministry of the Environment and Rural and Marine Affairs. 2010.

مع خالص شكري وامتناني

Thank you for your attention

Merci pour votre attention

For additional information please contact:

Sustainable Water Integrated Management – Support Mechanism: info@swim-sm.eu

Website: www.swim-sm.eu