Sustainable Water Integrated Management - Support Mechanism (SWIM- SM)

Project funded by the European Union

CSEI Catania
Centro Studi di Economia applicata all'Ingegneria

STUDY TOUR ON WASTEWATER MANAGEMENT
USING NATURAL TREATMENT SYSTEMS (NTS) IN RURAL AREAS

Selection criteria and design models of NTSs

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Catania, (Italy) 27 July 2015

Introduction

- Constructed wetlands
  - Reed’s method
  - Kadlec and Knight design method
- Waste Stabilization Ponds
  - Design of anaerobic ponds
  - Design of facultative ponds
  - Design of maturation ponds
- Wastewater storage reservoir

Constructed wetlands Design method

National experience and capacity needs for the construction and operation of NTSs

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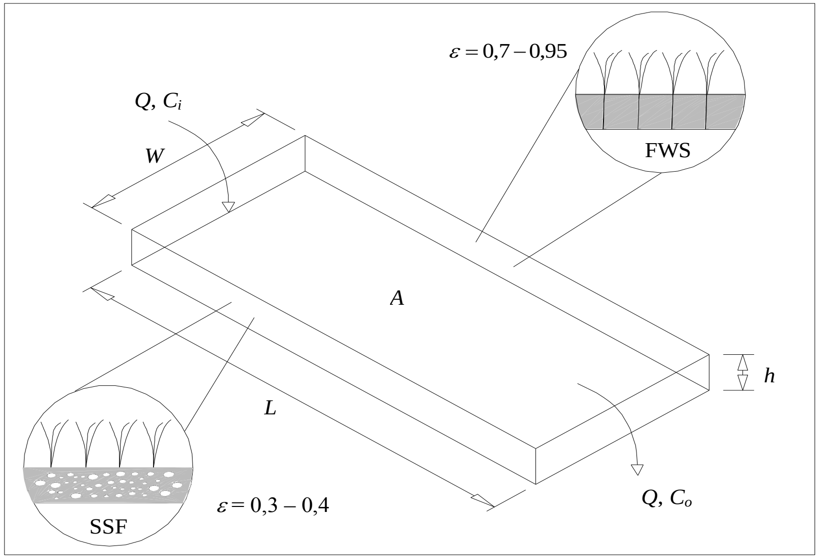
Design parameters for constructed wetland



C_i , C_o = **inflow and outflow CW concentration (mg/L);**

$Q = Q_i = Q_o$ = **volumetric flow rate (m³/d) with** $I = P = ET = 0$**;**

A = **Surface Area (m²);**

Mathematical model

h = **water depth (m);**

H-SSF: 0,2 – 0,8 m;
FWS: 0,1 – 1 m (tretment type; macrophyte)

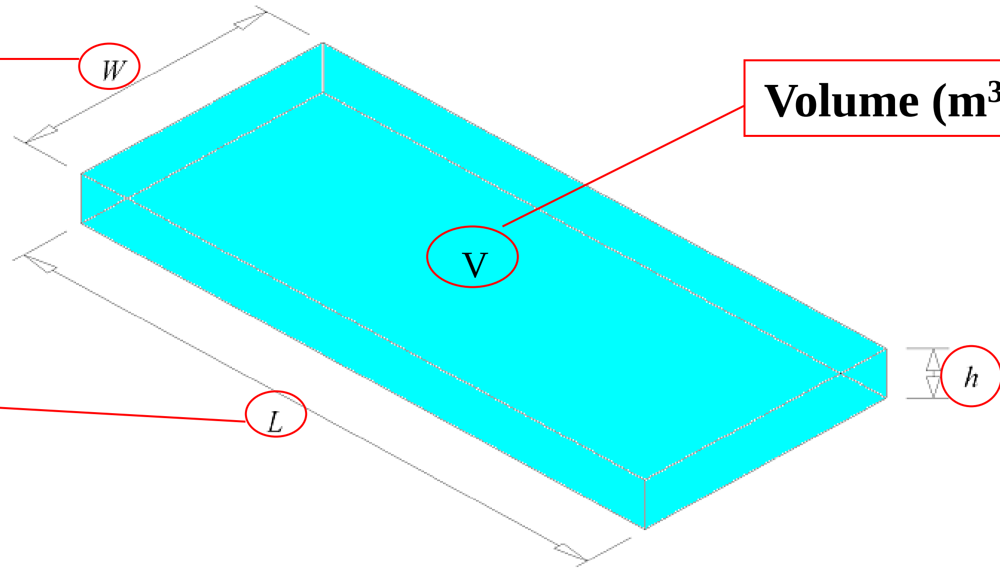
ε = **wetland Porosity (m³/m³).**

SSF: medium layer
FWS: density plant

Design parameters for constructed wetland

Witdh (m)

Volume (m^3)



Water depth (m)

Length (m)

$$A = L \cdot W$$ → **Srface Area (m^2)**

porosity (m^3/m^3)

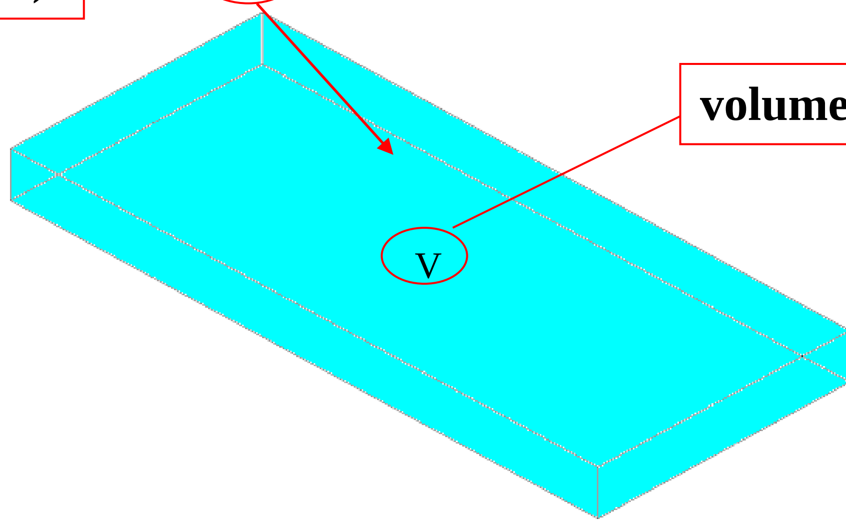
$$V = A \cdot h \cdot \varepsilon$$ → **Reaction Volume (m^3)**

Design parameters for constructed wetland

Volumetric Flow rate (m^3/d)

Q

volume (m^3)



$$HRT = \frac{V}{Q} = \frac{A \cdot h \cdot \varepsilon}{Q} = \frac{h \cdot \varepsilon}{q}$$

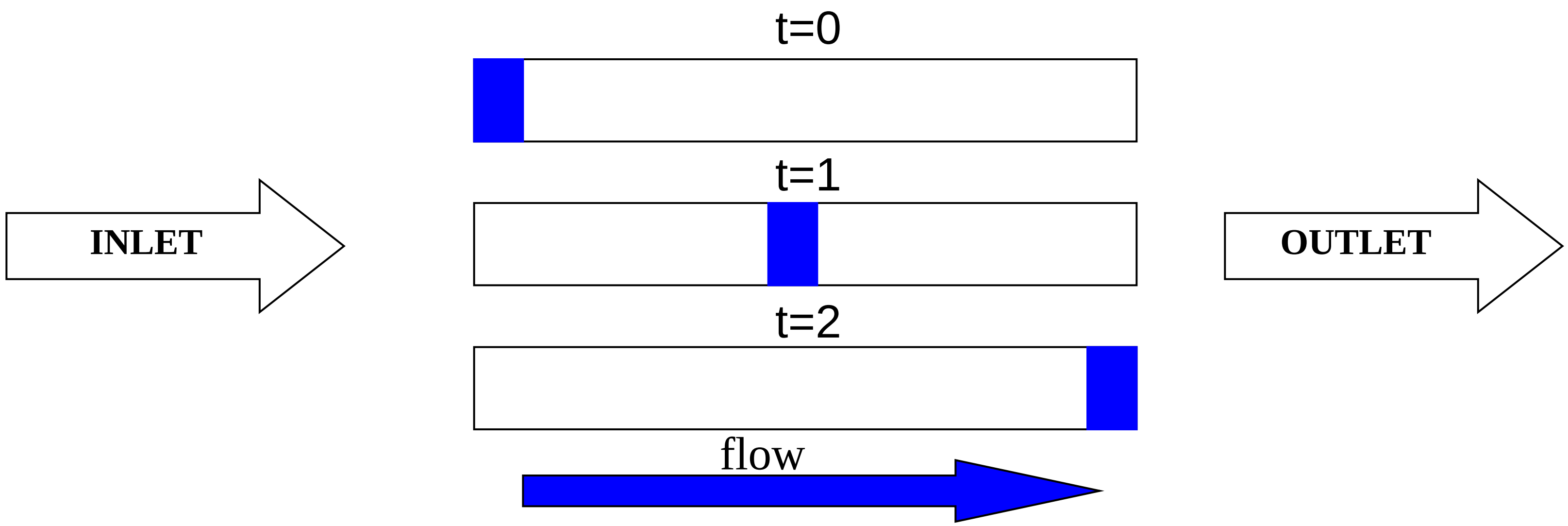
→ **Nominal detention Time (d)**

$$q = \frac{Q}{A}$$

→ **Hydraulic loding rate (m/d)**

Mathematical model

The wetland is designed assuming *plug flow model* and *first order reaction model*



k-C* model (Kadlec e Knight, 1996)

C_i = inflow concentration (mg/L)
C_o = outflow concentration (mg/L)
C^* = irreducible background concentration (mg/L)

If the pollutant removal is proportional to the volume (V) of water in the wetland

$$\frac{C_o - C^*}{C_i - C^*} = \exp\left(-k_V \cdot HRT\right)$$

$$HRT = \frac{V}{Q}$$

$$V = -\frac{Q}{k_V} \cdot ln\left(\frac{C_o - C^*}{C_i - C^*}\right)$$

volume (m³)

Flow rate (m³/d)

k_V = first order volumetric rate costant (d^{-1})

$$k_V = \frac{k_A}{\varepsilon \cdot h}$$

k_A = uptake rate constant (m/d)

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

k_{20} = uptake rate constant at 20°C (m/d)

θ = Temperature correction factor

T = wastewater temperature °C

k-C* model (Kadlec e Knight, 1996)

C_i = inflow concentration (mg/L)
C_o = outflow concentration (mg/L)
C^* = irreducible background concentration (mg/L)

If the pollutant removal is proportional to the immersed area (A) of biomaterial:

$$\frac{C_o - C^*}{C_i - C^*} = exp\left(-\frac{k_A \cdot A}{Q}\right)$$

$$A = -\frac{Q}{k_A} \cdot ln\left(\frac{C_o - C^*}{C_i - C^*}\right)$$

k_A = uptake rate constant (m/yr)

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

area (m^2)

Flow (m^3/d)

k-C* model (Kadlec e Knight, 1996)

Parameter	BOD	TSS	OrgN	NH_4-N	No_x-N	TN	TP[a]	FC
For free water surface wetlands:								
k_{20} (m/yr)	34	1000[b]	17	18	35	22	12	75
Q	1.00	1.00	1.05	1.04	1.09	1.05	1.00	1.00
C* (mg/l)	$3.5+0.053C_i$	$5.1+0.16C_i$	1.50	0.00	0.00	1.50	0.02	300[c]
q	1.00	1.065						
For sub-surface flow wetlands:								
k_{20} (m/yr)	180	1000b	35	34	50	27	12	95
q	1.00	1.00	1.05	1.04	1.09	1.05	1.00	1.00
C* (mg/l)	$3.5+0.053C_i$	$7.8+0.063C_i$	1.50	0.00	0.00	1.50	0.02	10[c]
q	1.00	1.065						

k-C* model (Kadlec e Knight, 1996)

Reed, Crites & Middlebrooks (1998)

C_i = inflow concentration (mg/L)
C_o = outflow concentration (mg/L)

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

$$\frac{C_o}{C_i} = \exp\left(-k_T \cdot HRT\right)$$

k_T = temperature-dependent rate constant (d^{-1}):

T = wastewater temperature (°C)

$$HRT = \frac{A \cdot h \cdot \varepsilon}{Q}$$

BOD_5 parameter values:

θ = 1,06

k_{20} = 20 °C uptake rate constant = 0,678 d^{-1} (FWS) or 1,104 d^{-1} (H-SSF)

$$A = \frac{Q \cdot \ln(C_i / C_o)}{K_T \cdot h \cdot \varepsilon}$$

Mathematical model (FWS): Manning's equation

$$v = \frac{1}{n} \cdot \left(h^{2/3}\right) \cdot \left(s^{1/2}\right)$$

v = average flow velocity (m/s)

s = hydraulic gradient or slope of water surface (m/m)

n = Manning's resistance coefficient (s/m$^{1/3}$) $\Rightarrow$ $n = \frac{a}{h^{1/2}}$

h = average wetland depth (m)

a = resistance factor (s·m$^{1/6}$);

= 0,4 s·m$^{1/6}$ for spare,low-standing vegetation, h > 0,4 m;

= 1,6 s·m$^{1/6}$ for moderate dense vegetation in wastewater wetland with $h \cong$ 0,3 m;

= 6,4 s·m$^{1/6}$ for very dense vegetation and litter layer with $h \leq$ 0,3 m.

In most situations, it is acceptable to assume value of a lies between 1 and 4 s·m $^{1/6}$

Mathematical model (FWS): Manning's equation

$$v = \frac{1}{a} \cdot \left(h^{7/6}\right) \cdot \left(s^{1/2}\right)$$

Flow (m³/d)

Increment depth factor

area (m²)

$$v = \frac{Q}{W \cdot h} \qquad W = \frac{A}{L} \qquad s = \frac{m \cdot h}{L}$$

width (m)

Water depth (m)

lenght (m)

Rearrangement of these term it's obtained maxim Length of FWS:

$$L = \left[\frac{A \cdot \left(h^{8/3}\right) \cdot \left(m^{1/2}\right) \cdot 86400}{a \cdot Q} \right]^{2/3}$$

Mathematical model (H-SSF): Darcy's Law

$$v = k_s \cdot s$$

v **= flow velocity (m/d)**

s **= hydraulic gradient (m/m)**

K_s **= hydraulic conductivity, (m/d)**

Flow (m^3/giorno)

$$v = \frac{Q}{W \cdot h}$$

width (m)

Water depth (m)

Mathematical model (H-SSF)

$$Q = k_s \cdot W \cdot h \cdot s \quad \Rightarrow \quad Q = k_s \cdot A_T \cdot s$$

A_T = cross-sectional area (m^2)

width (m)

$$W = \frac{A}{L}$$

area (m^2)

length (m)

hydraulic gradient (m/m)

Increment depth factor

$$s = \frac{m \cdot h}{L}$$

Water depth (m)

length (m)

$$W = \frac{1}{h} \cdot \left[\frac{Q \cdot A}{m \cdot k_s} \right]^{1/2}$$

design parameter for V-SSF

The principal design parameter for V-SSF system is Surface area tightly correlated on oxygen available to degrade the organic matter and nitrogen.

To this propose, It's assume that:

- ✓ 1 Kg O_2 is required for degrade 1 Kg BOD_5 and 4,3 Kg O_2 is required for degrade 1 Kg NH_3;
- ✓ Surface required (m^2):

Oxygen demand

$$A = \frac{OD}{K_a} + \frac{OD}{K_a} \cdot 0,25$$

Security factor

K_a= air transfer coefficient at surface → **30 g O_2/m^2**

Design procedure for H-SSF: example

date:

$Q = 150\ m^3/d$

$BOD_5 = 300\ mg/L$

$T = 12\ °C$

$K_s = 10.000\ m/d$

Wastewater primary sedimentation in imhoff tank

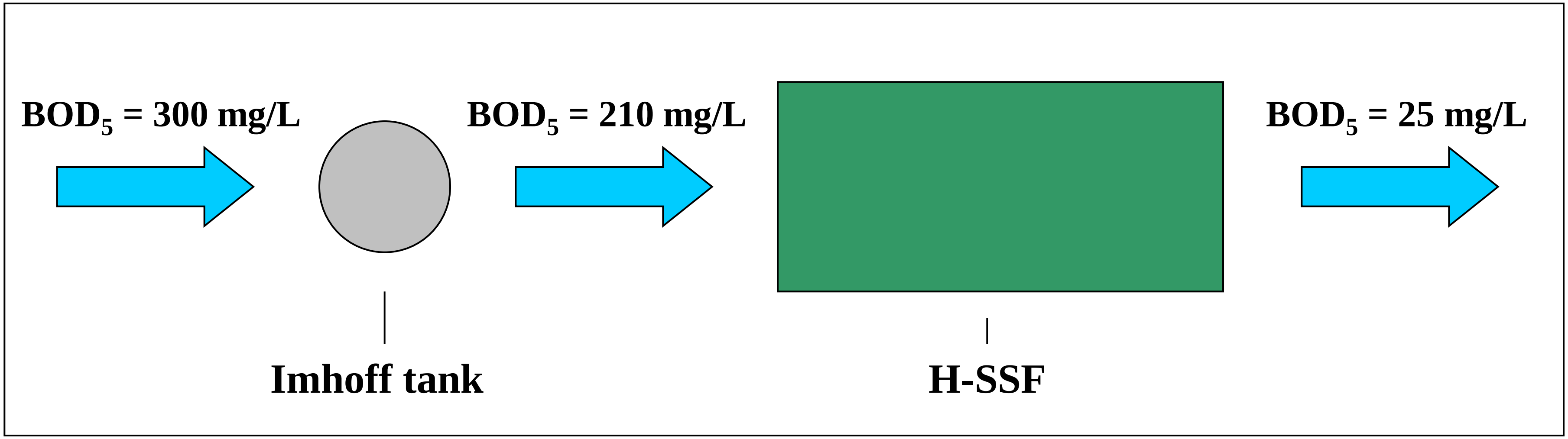
30% BOD_5 removal

$C_i = 210\ mg/L$ (BOD_5 the CW influent)

Italian surface water standards (D.Lgs. 152/2006)

$C_o = 25\ mg/L$ (BOD_5 in the CW effluent)

in



Design procedure for H-SSF: example

Application of Reed, Crites & Middlebrooks 1998 model

Uptake constant rate:

$$k_{12} = k_{20} \cdot \theta^{(T-20)} = 1{,}104 \cdot 1{,}06^{(12-20)} = 0{,}693\,\text{day}^{-1}$$

Nominal retention time:

$$HRT = -\frac{1}{k_T} \cdot \ln\left(\frac{C_o}{C_i}\right) = -\frac{1}{0{,}693} \cdot \ln\left(\frac{25}{210}\right) = 3{,}1\,\text{day}$$

Design procedure for H-SSF: example

Volume:

$$V = HRT \cdot Q = 3{,}1 \cdot 150 = 465\,\mathrm{m}^3$$

Surface area:

$$A = \frac{V}{h \cdot \varepsilon}$$

$$h = 0{,}55\,m$$

$$\varepsilon = 0{,}38\,\mathrm{m}^3/\mathrm{m}^3$$

$$A = \frac{465}{0{,}55 \cdot 0{,}38} = 2225\,\mathrm{m}^2$$

Design procedure for H-SSF: example

reed bed minimum width :

$$W = \frac{1}{h} \cdot \left[\frac{Q \cdot A}{m \cdot k_s} \right]^{1/2} = \frac{1}{0{,}55} \cdot \left[\frac{150 \cdot 2225}{0{,}2 \cdot 3500} \right]^{1/2} = 40\ \mathrm{m}$$

20% of Hydraulic head

1/3 of Hydraulic conductivity

Reed bed Length :

$$L = \frac{A}{W} = \frac{2225}{40} = 56\ \mathrm{m}$$

Length /width ratio:

$$L : W = 56 : 41 = 1{,}4 : 1$$

OK
It's incluse between:
1:1 and 3:1

Data:

$Q = 150\ m^3/d$

$BOD_5 = 300\ mg/L$

$T = 9\ °C$

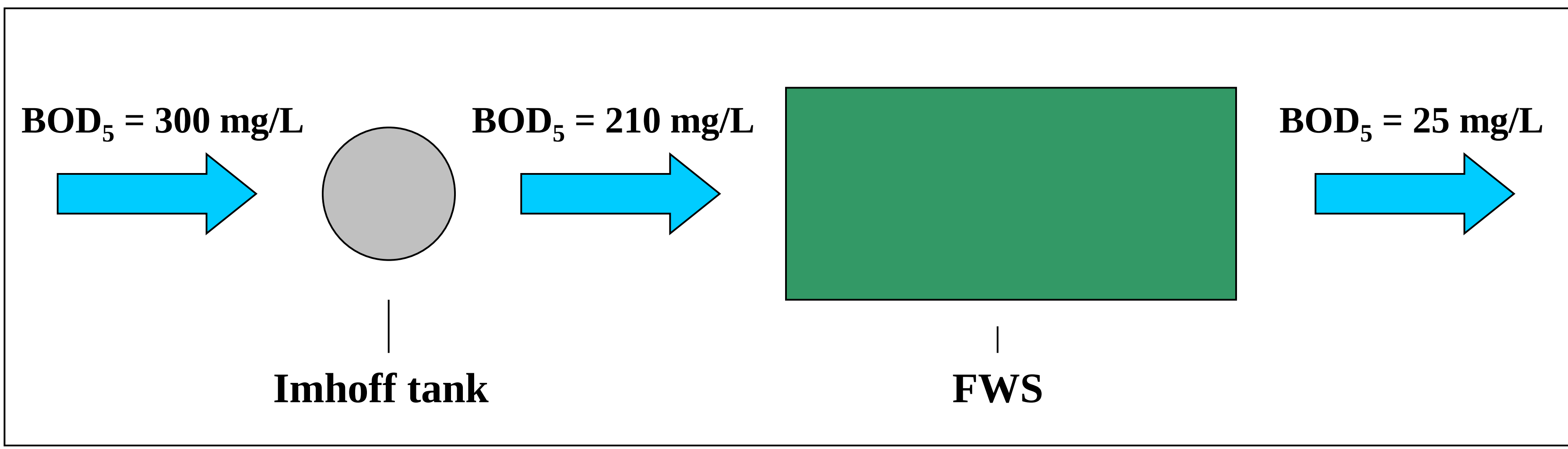
Wastewater primary sedimentation in imhoff tank

30% BOD_5 removal

$C_i = 210\ mg/L$ (BOD_5 in the CW influent)

Italian surface water standards (D.Lgs. 152/2006)

$C_o = 25\ mg/L$ (BOD_5 in the CW effluent)



Design procedure for H-SSF: example

Uptake constant rate:

$$k_9 = k_{20} \cdot \theta^{(T-20)} = 0{,}678 \cdot 1{,}06^{(9-20)} = 0{,}357 \text{ day}^{-1}$$

Nominal retention time:

$$HRT = -\frac{1}{k_T} \cdot \ln\left(\frac{C_o}{C_i}\right) = -\frac{1}{0{,}357} \cdot \ln\left(\frac{25}{210}\right) = 5{,}96 \text{ day}$$

Volume

$$V = HRT \cdot Q = 5{,}96 \cdot 150 = 894 \text{ m}^3$$

Design procedure for H-SSF: example

Surface Area:

$$A = \frac{V}{h \cdot \varepsilon}$$

$$h = 0{,}30\ m$$

$$\varepsilon = 0{,}75\ \mathrm{m}^3/\mathrm{m}^3$$

$$A = \frac{894}{0{,}30 \cdot 0{,}75} = 3973\ \mathrm{m}^2$$

Design procedure for FWS: example

Reed bed maximum Length :

$$L = \left[\frac{A \cdot \left(h^{8/3}\right) \cdot \left(m^{1/2}\right) \cdot 86400}{a \cdot Q} \right]^{2/3}$$

m = 0,2

a = for moderately dense vegetations = 1,6 s·m$^{1/6}$

$$L = \left[\frac{3973 \cdot \left(0{,}30^{8/3}\right) \cdot \left(0{,}2^{1/2}\right) \cdot 86400}{1{,}6 \cdot 150} \right]^{2/3} = 876\ \mathrm{m}$$

Reed bed Length

$$L = \frac{A}{W} = \frac{3973}{876} = 4{,}5\ \mathrm{m}$$

Design procedure for FWS: example

Length /width ratio:

$$L:W = 876:4{,}5 = 194{,}7:1$$

NO
It is no incluse between
2:1 and 10:1

$$W = 20\ \mathrm{m} \qquad L = 200\ \mathrm{m}$$

Length /width ratio: :

$$L:W = 200:20 = 10:1$$

OK
It's incluse between
2:1 and 10:1

Comparison with H-SSF and FWS

Data :

$Q = 150\ m^3/d$

$C_i = 210\ mg/L\ (BOD_5)$

$C_o = 25\ mg/L\ (BOD_5)$

H – SSF	**FWS**
$A = 2225\,\mathrm{m}^2$	$A = 3973\,\mathrm{m}^2$

$\Downarrow$

FWS ≈ 2 H-SSF

H-SSF Design procedure for 4 p.e.

Data:

$Q = 1\ m^3/d$

$BOD_5 = 300\ mg/L$

$T = 12\ °C$

$K_s = 10.000\ m/d$

Wastewater primary sedimentation in imhoff tank

30% BOD_5 removal

$C_i = 210\ mg/L$ (BOD_5 in the CW influent)

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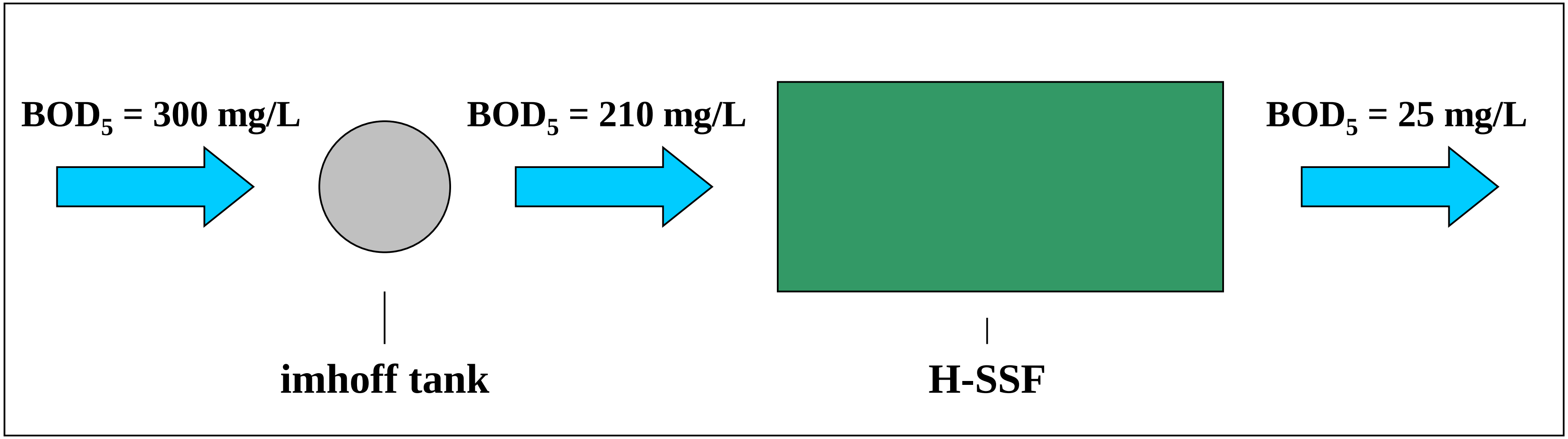
$C_o = 25\ mg/L$ (BOD_5 in the CW effluent)



H-SSF Design procedure for 4 p.e.

Reed, Crites & Middlebrooks 1998 model

Uptake rate constant:

$$k_{12} = k_{20} \cdot \theta^{(T-20)} = 1{,}104 \cdot 1{,}06^{(12-20)} = 0{,}693\,\text{day}^{-1}$$

Hydraulic retention Time

$$HRT = -\frac{1}{k_T} \cdot \ln\left(\frac{C_o}{C_i}\right) = -\frac{1}{0{,}693} \cdot \ln\left(\frac{25}{210}\right) = 3{,}1\,\text{day}$$

H-SSF Design procedure for 4 p.e.

Volume:

$$V = HRT \cdot Q = 3{,}1 \cdot 1 = 3{,}1\,\mathrm{m}^3$$

Surface Area:

$$A = \frac{V}{h \cdot \varepsilon}$$

$$h = 0{,}55\,m$$

$$\varepsilon = 0{,}38\,\mathrm{m}^3/\mathrm{m}^3$$

$$A = \frac{3{,}1}{0{,}55 \cdot 0{,}38} = 14{,}8\,\mathrm{m}^2$$

H-SSF Design procedure for 4 p.e.

reed bed minimum width:

$$W = \frac{1}{h} \cdot \left[\frac{Q \cdot A}{m \cdot k_s} \right]^{1/2} = \frac{1}{0{,}55} \cdot \left[\frac{1 \cdot 14{,}8}{0{,}2 \cdot 3500} \right]^{1/2} = 0{,}26 \text{ m}$$

20% of Hydraulic head

1/3 of Hydraulic conductivity

Reed bed Length :

$$L = \frac{A}{W} = \frac{14{,}8}{0{,}26} = 56{,}9 \text{ m}$$

H-SSF Design procedure for 4 p.e.

Length /width ratio:

$$L:W = 56{,}9:0{,}26 = 219:1$$

NO
It's not incluse
between 1:1 and 3:1

$$W = 2{,}50\ \mathrm{m} \qquad L = 6{,}00\ \mathrm{m}$$

Length /width ratio:

$$L:W = 6{,}00:2{,}50 = 2{,}4:1$$

OK
It is incluse between:
1:1 and 3:1

Waste Stabilization Ponds
Design method

National experience and capacity needs for the construction and operation of NTSs

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Design criteria of Anaerobic ponds

- The design of anaerobic ponds is not well defined and a widely accepted overall design equation does not exist. Design is often based on organic loading rates, surface or volumetric loading rates and HRT derived from pilot plant studies and observations of existing operating systems.
- The volume of anaerobic pond is related to the organic loading as follow:

$$V = \frac{C_{BOD}}{C_{ov}}$$

C_{BOD} → organic loading (g BOD_5/d)

C_{ov} → volumetric organic loading (g BOD_5/m^3 d)

Temperate (°C)	C_{ov} (g BOD_5/m^3 d)	removal BOD %
≤ 10	100	40
10-20	20·T-100	2·T+20
20-25	10·T+100	2·T+20
≥ 25	350	70

(Mara e Pearson, 1998)

- The detention time td (day):

$$t_d = \frac{V}{Q}$$

V → volume of anaerobic pond (m^3)

Q → Flow rate (m^3/ d)

Design criteria of Facultative ponds

- The design equation assumes that Organic matter removal in the Facultative Lagoons follows first-order Kinetic and that the pond are completely mixed. The resulting equation is:

$$\frac{C_0}{C_i} = \frac{1}{1 + K_T \cdot t_d} \longrightarrow t_d = \frac{1}{K_T} \cdot \left(\frac{C_i}{C_0} - 1 \right)$$

- t_d = detention time (d);
- K_T = first order rate costant (d^{-1});
- ***Ci*** and ***Co*** = BOD5 concentration, in the influent and in the effluent respectively (mg/L).

- The value of K_T at various temperature is given by:

$$K_T = 1{,}2 \cdot (1{,}085)^{(T-35)}$$

Temperature (°C)	K_T (day^{-1})
5	0,104
10	0,156
15	0,235
20	0,353
25	0,531
30	0,798
35	1,200

- The Surface Area (S, m^2) of Facultative Lagoons is given by:

$$S = \frac{Q}{h \cdot K_T} \cdot \left(\frac{C_i}{C_o} - 1 \right)$$

Design criteria of Facultative ponds

- first-order Kinetic can be use also for microbiological parameters removal:

$$\frac{N_0}{N_i} = \frac{1}{1 + K_b \cdot t_d}$$

  - ***td*** : detention time (d);
  - ***Kb*** : first order rate costant (d^{-1});
  - ***Ni and No*** = coliform faecal concentration/100 ml, in the influent and in the effluent of the pond respectively

$$K_b = 2{,}6 \cdot (1{,}19)^{(T-20)}$$

$$T = 14\text{-}30°C \longrightarrow K_b = 0{,}712 \cdot (1{,}166)^{(T-20)}$$

Design criteria of Facultative ponds

- first-order Kinetic can be use also for <u>nutrients removal</u> (Pano e Middlebrooks, 1983):
  - T < 30°C:

$$C_o = \frac{C_i}{\{1+[(S/Q)\cdot(0{,}0038+0{,}000134\cdot T)\cdot \exp((1{,}041+0{,}044\cdot T)\cdot(pH-6{,}6))]\}} \qquad \mathbf{1}$$

  - T > 30°C:

$$C_o = \frac{C_i}{\{1+[0{,}005\cdot(S/Q)]\cdot[\exp(1{,}540\cdot(pH-6{,}6))]\}} \qquad \mathbf{2}$$

$$C_o = C_i \cdot \exp\left(-\left(0{,}00064\cdot(1.039)^{T-20}\right)\cdot(t_d+60{,}6\cdot(pH-6{,}6)\right) \qquad \mathbf{3}$$

Co: Ammonia-nitrogen effluent concentration in the (1) e (2) and total ammonia effluent concentration in the (3) (mg N/L);
Ci: Ammonia-nitrogen influent concentration in the (1) e (2) and total ammonia effluent concentration in the (3) (mg N/L);
T : air tempertaure between 1 and 38°C;
T_d: detention time (d) between 5 and 330 days.

Design of maturation ponds

- The method of Marais (1974) is generally used to design a pond series for faecal coliform removal.

$$N_e = \frac{N_i}{(1 + k_T \theta)}$$

- Where
  - N_e and N_i are the number of faecal coliform/100 ml in the effluent and influent
  - k_T is the first-order rate constant for faecal coliform removal (d^{-1})
  - θ is a retention time (day)
- The value of kT is highly temperature-dependent. Marais (1974) found that

$$k_T = 2.6\,(1.19)^{T-20}$$

kT changes by 19% for every change in temperature of 1o C.

- The maturation pond area is calculated from

$$A_m = 2Q_i\theta_m / (2D + 0.001e\theta_m)$$

Flow rate (m^3/ d)

is the pond depth (m)

Wastewater storage reservoir Design method

National experience and capacity needs for the construction and operation of NTSs

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Wastewater storage reservoir: mean residence time (*MRT*)

- Juanicó and Friedler (1994) and then Cirelli et al., (2009) and Consoli et al. (2011) introduced the importance of operational parameters by comparing the mean residence time (*MRT*) and the percentage of fresh effluent (*PFE*) within the reservoir. The following equation was developed to calculate the mean residence time in WSR, at the end of a given day *d* (when there is no outflow from the reservoir), and under the assumption of perfect mixing:

$$MRT_d = \frac{[(MRT_{d-1} + 1) \cdot VOL_{d-1}] + (IN_d / 2)}{(VOL_{d-1} + IN_d)}$$

- IN_d is the volume of wastewater (m^3) entering the reservoir during the day *d*;
- VOL_d is the volume of wastewater (m^3) stored in the reservoir on day *d*.

Wastewater storage reservoir: percentage of fresh effluent (*PFE*)

- Some effluents have resided in the reservoir for some time, while some of them were just introduced: **PFE** is the fraction of fresh effluent over the total volume within the reservoir. For example, PFE of 5 days (PFE5) is the volume of effluents having resided in the reservoir 5 days or less, expressed as a percentage of total reactor contents:

$$PFE5_d = \frac{\sum_{i=d-(n-1)}^{i=d}\left(IN_i - IN_i\frac{OUT_i}{VOL_i}\right) - \left(IN_{d-1} - IN_{d-1}\frac{OUT_{d-1}}{VOL_{d-1}}\right)\cdot\frac{OUT_d}{VOL_d}}{V_d}\cdot 100$$

where:

- n is the residence time of the effluent in the reservoir;
- OUT_i is the volume of effluent (m^3) withdrawn on day i;
- $IN_i \cdot \frac{OUT_i}{VOL_i}$ is the reduction of input volume IN_i due to volume withdrawn OUT_i;
- $\left(IN_{d-1} - IN_{d-1}\frac{OUT_{d-1}}{VOL_{d-1}}\right)\cdot\frac{OUT_d}{VOL_d}$ is the reduction of volume IN_{d-1} due to volume withdrawn OUT_d.

Wastewater storage reservoir: MRT and PFE

- In the case of reservoirs that operate as accumulative batch reactors, both MRT and PFE vary continuously through the year: MRT continues to increase during the winter, reaching a maximum towards the middle of the irrigation season; PFEn with high value of n (≥ 30 days) decreases during the non-irrigation season, because of the growing volume inside the reservoir, and greatly increases during the irrigation season, due to the continuous reduction of stored volume, which in turn leads to reduced dilution of the wastewater influent.
- Experimental results (Juanico and Friedler, 1994; Barbagallo *et al*., 2002, Cirelli et al., 2009; Consoli et al., 2011) confirm that PFE is a better descriptor of reactor performance than the mean residence time. MRT relies on the hydraulic age distribution of the entire wastewater volume, while PFE depends only on the small portion of fresh effluents that actually determine the reactor's performance.
- However, when the reservoir operates in a batch mode (i.e. the case of small reservoirs), the volume is filled all at once, therefore decreasing the significance of the operational parameter PFE and increasing that of MRT.

EXPERIENCE IN SICILY: Modelling Wastewater Reservoir Operation

- Individuation of wastewater reservoirs operational parameters related to the removal processes of the main bacteriological pollutants
- Definition of a new operational parameter "MRT%FE" for wastewater reservoirs. It represents the mean residence time of different freshest effluent percentages (FE) within a reservoir
- A model was developed to calculate the parameter MRT%FE of different fresh effluent percentages (10, 20, 33, 50%) within a wastewater reservoir (Cirelli et al., 2008).

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Journal of Environmental Management 90 (2009) 604–614

Journal of Environmental Management

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Modelling *Escherichia coli* concentration in a wastewater reservoir using an operational parameter MRT%FE and first order kinetics

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Received 8 February 2007; received in revised form 15 November 2007; accepted 11 December 2007
Available online 28 January 2008

A simplified method to calculate the percentage of fresh effluents (PFE) in non-steady state reactors

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Abstract

Storage reservoirs are a key element in wastewater treatment trains for agricultural reuse; however, there is a need for further research on design criteria and operation rules for such reactors. The percentage of fresh effluents (PFE) is an important parameter for the design of perfectly-mixed reactors. PFE correlates better than mean residence time with the performance of the reactor. It allows for estimation of the removal of pollutants in non steady-state systems, such as seasonal wastewater storage reservoirs, and for forecasting the quality of the effluents released for irrigation. However, calculation of PFE is a difficult process requiring complex computer algorithms. A simplified analytical approach is developed to calculate the PFE for *n* days. The formulation is discussed, describing the relationships between the hydraulic variables, and then applied to a non-steady-state continuous-flow wastewater reservoir in Eastern Sicily (Italy).

Keywords: hydraulic age distribution, perfectly-mixed reactor, mean residence time, wastewater storage reservoirs

Water SA Vol. 37 No. 4, 2011

EXPERIENCE IN SICILY: Modelling Wastewater Reservoir Operation

$$MRT100FE = \frac{VOL_I \times [(MRT_{I-1} + 1) + (I_I \times 0.5)]}{VOL_I + I_I}$$

MEAN RESIDENCE TIME OF THE FRESHEST EFFLUENT

$$N_d = \frac{N_{od}}{1 + [(MRT\%FE_d) \cdot K_T]}$$

THE USE OF FIRST ORDER KINETICS

- The use of MRT%FE has evidenced that *E.coli* removal is strongly influenced by 50% of freshest effluent stored within the reservoir,
- The **MRT50FE** is of about 8 days (**Tracer test**)
- The removal efficiency of *E.coli* using MRT%FE is of 3 log units
- Significant correlations were found between KT and the incident solar radiation (I) and water temperature (Tw) at the different reservoir depth