Constructed wetlands for wastewater treatment

Definition

Constructed wetlands can be defined as engineered water saturated areas in which the natural removal processes for the water pollutants are reproduced and enhanced in order to optimize the purification performances.

Constructed wetlands – 1

Definition

A main part of the pollutants contained in wastewater are nutrients that can be removed in wastewater treatment plants by reproducing natural self-purification processes. Conventional treatment plants like activated sludge plants enforce biological organisms with energy-intensive mechanical equipment to decompose complex compounds, to incorporate the nutrients in biomass and finally to separate that biomass from the purified water. Thus such plants are energy intensive reactors with relatively small area demand that are suitable for centralized wastewater treatment.

Constructed wetlands are principally using the same natural degradation processes and nutrient uptake but they are acting as “extensive systems”. The high degree of biodiversity present in these systems allows multiple and various degradation mechanisms for several classes of compounds, and therefore higher performances in comparison with the technological treatment plants in which only few families of specialised bacteria are grown. The purifying processes take place without input of “human produced” energy by, for instance, oxygenating pumps. Furthermore there is no excess sludge to be removed since there is a balance of biomass growth and decomposition in the constructed wetland system. As a compensation to the low energy demand there is a relatively large area demand. Accordingly constructed wetlands are usually suitable and cost effective for small and medium size wastewater treatment.

Within the last 20-30 years various types of constructed wetlands have been developed in different countries. There is a wide acceptance and interest within the population because of the following advantages:

- Less expensive to build than other treatment options
- Simple construction, operation and maintenance
- Low operation and maintenance costs
- High ability to tolerate fluctuations in flow and inlet quality
- High process stability (buffering effect)
- Sludge produced only by the primary treatment stage
- High pathogen removal – good water reuse and recycling options
- Optimal aesthetic appearance

Application Fields 1

POINT SOURCE POLLUTION:

Secondary treatment of the following kinds of wastewater:

- domestic
- municipal
- industrial

Tertiary treatment at a polishing stage in conventional treatment plants

Constructed wetlands – 2

Application fields 1

Domestic or municipal wastewater

Treatment of domestic or municipal wastewater is currently a conventional application. There are several thousand of operating constructed wetlands worldwide, since more than 15-20 years, and the most used are the subsurface flow systems. The most available sets of monitoring data (like as the North American Database, the UK Wrc database, several European collections and so on) are related to this kind of application.

Industrial wastewater

There are numerous possibilities also for industrial wastewater like chemical industry, laboratory effluents, landfills, acid mines... and agricultural or agro-food wastewaters like wineries, olive oil mills, dairy, and in general all the high organic content characterised waters.

Link:
www.wetlandsurvey.org

Literature for deepening:

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Cooper, P.F.;,Job G.D.; Green, M.B.; Shutes, R.B.E.: *Reed beds and constructed wetlands for wastewater treatment*. WRc plc; Swindon, UK 1996

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Kadlec R.H.; Knight R.L.: *Treatment Wetlands*. Lewis Publisher CRC press; Florida 1996

Vymazal, J.; Brix, H.; Cooper, P.F.; Green, M.B.; Haberl, R.: *Constructed wetlands for wastewater treatment in Europe*. Backhuys Publishers; Leiden, The Netherlands 1998

Application Fields 2

DIFFUSE POLLUTION:

Agricultural Runoff

Urban Runoff

Highway Runoff

Airport Runoff

Polluted Surface Waters and Growndwaters

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Application fields 2

A lately developed application of constructed wetland is related to the diffuse (or non-point) pollution treatment. Several kinds of diffuse pollution, like agricultural or urban or infrastructures runoff can be faced using extensive natural treatments, which effectiveness in the removal of nutrients (Nitrogen and Phosphorous) and micropollutants, like persistent organic compounds (i.e. Polyciclic Aromatic Hydrocarbons generated by vehicles fuel engines) makes this kind of techniques very suitable for watershed scale approaches wherever a specific local treatment turns out to be inapplicable.

Due to the commonly very high amount of needed surface for this kind of applications, the most used systems are the Free Water Surface (FWS) constructed wetlands; their realisation and maintenance costs expenses are in fact observably lower than the subsurface systems, not considering the added values produced by their high naturality and the acceptability and the enrichment of the environment as of the biodiversity.

Literature for deepening:

Vymazal J.: *Transormation of Nutrients in Natural and Constructed Wetlands*. Backhuys Publisher; Leiden 2001

Crumpton W.G.: *Using wetlands for water quality improvement in agricultural watersheds: the importance of a watershed scale approach*. Water Science & Technology, Vol. 44, No..11/12, pp 559-564, 2001

Revitt D.M.; Worrall P.; Brewer D.: *The integration of constructed wetlands into a treatment system for airport runoff*. Water Science & Technology, Vol. 44, No. 11/12, pp 469-476, 2001

Shutes B. et al.: *An experimental constructed wetland system for the treatment of highway runoff in the UK*. Water Science & Technology, Vol. 44, No. 11/12, pp 571-578, 2001

Application Fields 3

PARTICULAR APPLICATIONS:

- Landfill leachate

- Sludge dewatering and mineralisation

Constructed wetlands – 4

Application fields 3

Rain and other liquid that flows through the landfill comes into contact with buried waste. The liquid is called leachate and picks up many contaminants on its way to the bottom of the landfill. Leachate must be treated before it can be safely returned to the environment. Usually this leachate is collected into dedicated tanks and then transported to large wastewater treatment plants, but local treatments seem to be a preferable option for several aspects. Constructed wetlands achieve interesting results for the leachate treatment, like as a very high removal of the main pollutants (organic matter, ammonia, nitrates, heavy metals,...) and reduction of the wastewater quantity for evapotranspiration.

Reed beds can also be used to dewater and stabilize excess sludge from technical plants. About the 70% of the operating Activated Sludge Plants in Denmark have adopted this kind of treatment instead of the existing mechanical processes. This application can also be used to treat the primary sludges (coming from Imhoff or septic tanks) in small or medium size facilities. The stabilized material have to be removed periodically (like every ten years, and, accordingly to its chemical quality, it can be used as soil fertiliser.

Literature for deepening:

Bulc T.; Vrhovsek D.; Kukanja V.: *The use of constructed wetland for landfill leachate treatment.* Water Science & Technology, Vol. 35, No. 5, pp 301-306, 1997

Martin C.D.; Moshiri G.A.; Miller C.C.: *Mitigation of landfill leachate incorporating in-series constructed wetlands of a closed-loop design.* In Constructed Wetlands for Water Quality Improvement, Moshiri G.A. Ed.; Lewis Publisher, London, pp 473-477, 1993

Mulamoottil G.; McBean E.A.; Rovers F.: *Constructed wetlands for the treatment of landfill leachates*. Lewis Publishers, 1999

Urbanc Bercic O.: *Investigation into the use of constructed reedbeds for municipal waste dump leachate treatment*. Water science and technology, Vol. 29, pp 289-294, 1994

Trautmann N.M.; Martin J.H.; Porter K.S.; Hawk K.C.: *Use of artificial wetlands for treatment of municipal solid waste landfill leachate*. In Constructed Wetlands for Wastewater Treatment, Hammer D.A. Ed.; Lewis Publisher, London, pp 245-253, 1989

Classification

TYPES OF MACROPHYTES USED

1. Floating macrophyte-based system
2. Submerged macrophyte –based system
3. Rooted emergent macrophyte –based system

DIFFERENT TYPES OF WATER FLOW DIRECTION

a) Systems with free water surface (FWS)
b) Systems with horizontal subsurface flow (SFS-h or HF)
c) Systems with vertical subsurface flow (SFS-v or VF)
d) Hybrid systems (combinations of a,b,c)

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Classification

Constructed wetlands can be classified according the life form of the macrophytes (plants) in the system:

1. Floating macrophyte-based system (i.e. Lemna spp or Eichornia crassipes)
2. Submerged macrophyte –based system (i.e. Elodea canadiensis)
3. Rooted emergent macrophyte –based system (i.e. Phragmites australis, Tipha spp,..)

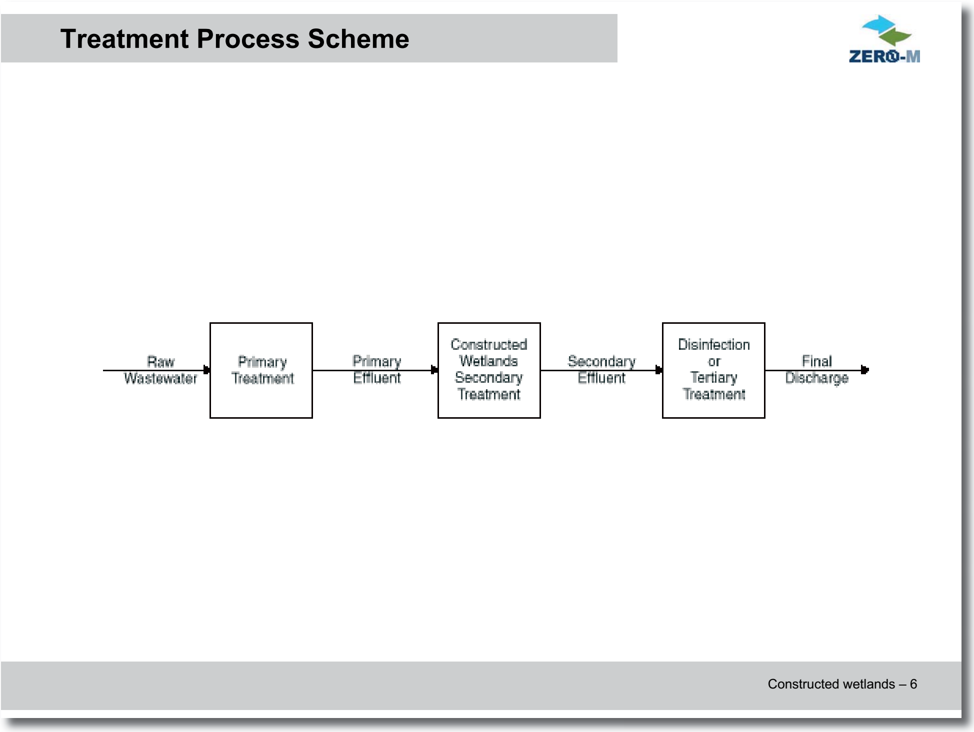
The third typology is described with more detail because it is the most common used in Europe and in the world. It can be categorized according to the flow pattern:

a) Systems with free water surface (FWS)
b) Systems with horizontal subsurface flow (SFS-h or HF)
c) Systems with vertical subsurface flow (SFS-v or VF)
d) Hybrid systems (combinations of a,b,c)

The most widespread systems are the subsurface flow systems and the free water surface systems. In the first type, the water flows under the ground, in a gravel bed located within a waterproof liner or layer, where vegetation species, usually the common reed, have been planted; the second type is represented by a series of shallow ponds containing different plants with various purification potentials (such as Phragmites, Scirpus, Tipha, submerged macrophytes).

Literature for deepening:

see pdf file ScienticReport8 on the CD (by International Water Association – Specialist group on the use of macrophytes for water pollution control)

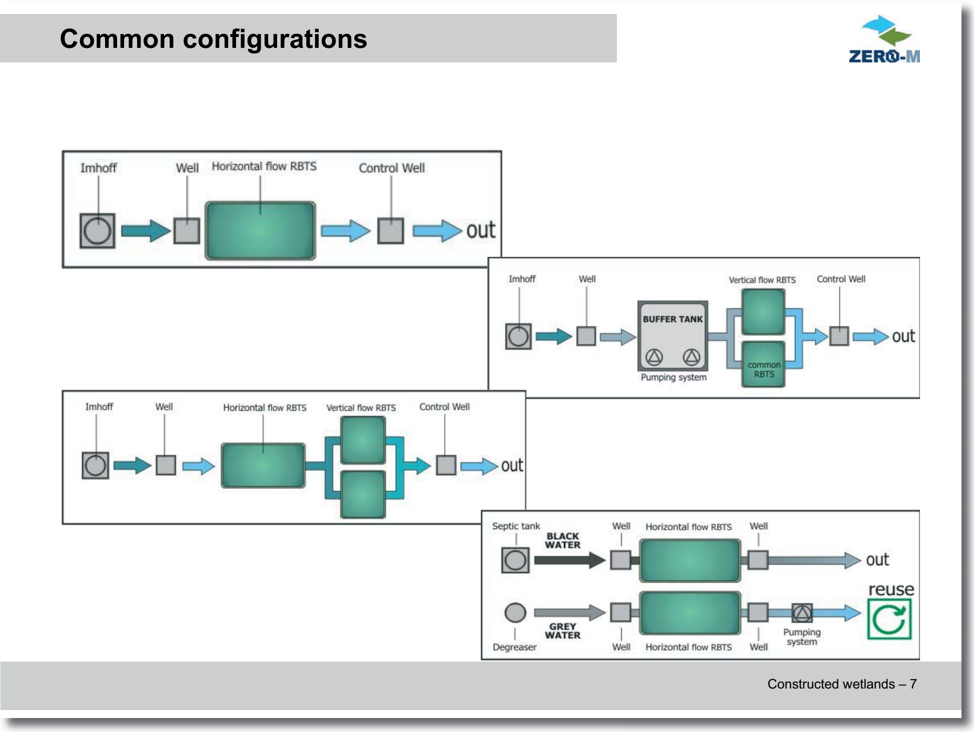


Treatment process scheme

The most common treatment scheme consists of a primary treatment by a filtration-sedimention device, like as septic or Imhoff thanks and often grids and degreasers, followed by a subsurface flow constructed wetland as secondary stage and then by a FWS CW as polishing stage.

When denitrification has to be obtained with a high N removal rate, the third stage should preferably be an horizontal flow reed bed.

The primary treatment should be sized with a volume per person of about 500-600 liters.



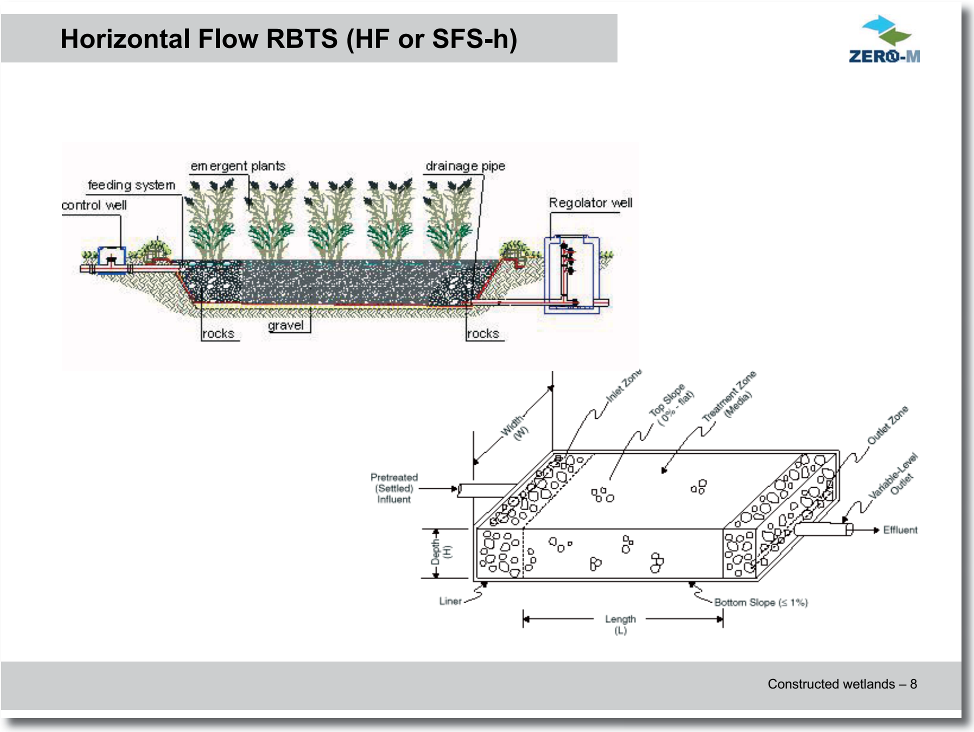
Common configurations

Some examples of common configurations are shown in this slide. The simplest one is a single HF reed bed, advicable when the requested treatment goal are limited to the Organic Content and Total Suspended Solids removal. This configuration has the simplest and cheapest management and for this reason is very affordable in the long period.

When a high removal of Ammonia is needed, it’s necessary to adopt a VF system, that needs a pumping system or an energy-free feeding system (like as syphons or floating valves or tipping buckets) to spread the wastewater in an alternate way on the bed surface. It’s normally advised to divide the needed surface in parallel beds, in order to permit a longer resting time after each load of the system.

Hybrid system, that are basically combinations of the three typologies, HF, VF and FWS, are the most effective in obtaining a very complete purification.

A remarkable optimization of the treatment scheme can be obtained with the segregation of black and grey wastewater, especially with the final aim of effluent reuse. In fact, greywater are more easily purified than the black ones, and the effluents are usually less contaminated by pathogens.



Horizontal flow RBTS

This type of RBTS consists in a properly designed basin that contains gravel or sand as substrate, wetland plants (normally Reeds) and microorganisms; the bed is fed with wastewater coming from a suitable primary treatment by a simple inlet device.

The subsurface horizontal flow systems (commonly named reed beds when planted with Phragmites) are most appropriate for treating primary wastewater, because there isn’t an atmosphere/water interface, and this fact makes this technology particularly safe from the public health point of view.

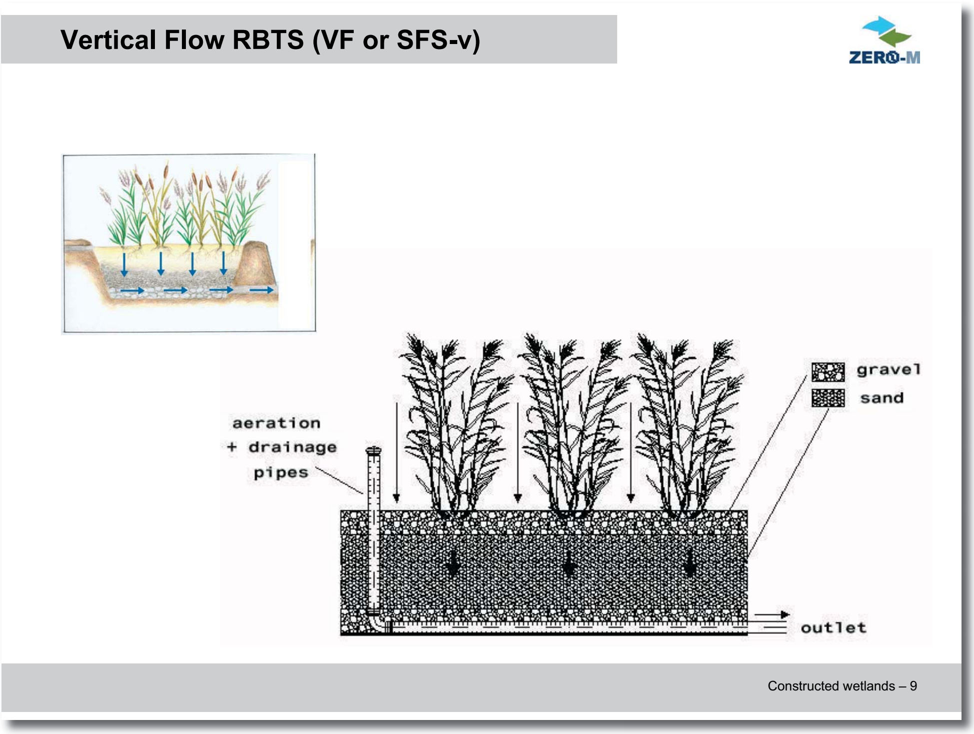
Therefore these systems are actually useful for on-site treatment of septic tank effluents and grey water. The HF systems are realized as gravel containing beds where the filling material is sized to offer an appropriate hydraulic conductivity (the most used media are coarse gravel, fine gravel and coarse sand) and to furnish a large available surface for the biofilm growing.

The beds are waterproofed by plastic membrane liners (HDPE or PVC) or clay. The water level remains always under the surface of the bed; the wastewater flows horizontally by a slope (about 1%) obtained by a sand layer under the membrane liner. The subsurface flow prevents odours and mosquitoes and permits public access in the wetland area. This kind of CW is particularly efficient in Suspended Solids, Carbon and Pathogens removal, as well as for Denitrification, while, due to its prevalently anoxic conditions, nitrification is quite limited.

The bed depth depends from the used macrophytes; when using Phragmites it’s commonly set to 0.6 – 0.7 meters.

The preferred values for the Widht/Lenght ratio are W/L > 1, with 3 meters < L < 30 meters.

In the inlet and outlet zones is advised to use a large filling material, like as stones, in order to ensure an easy cleaning if clogging happens.



Vertical flow RBTS

Vertical flow reed beds (VF) differ from the horizontal ones for the feeding method, the direction of the water flow and the filling media. In these systems the wastewater is applied through a distribution system on the whole surface area and passes the filter in a more or less vertical path. The pre-treated wastewater is dosed on the bed in a large batch (intermittent feeding), thus flooding the surface. During the time between the feedings the pores within the filter media can fill up with air which is trapped by the next dose of liquid. Thus oxygen requiring nitrifying bacteria are favoured and full nitrification can be achieved, but only a small part of the formed nitrate is denitrified under aerobic conditions. The denitrification and thus total nitrogen elimination can be increased by a partial recirculation of the nitrified effluent into the first chamber of the septic tank. The treated water is collected in a bottom drainage system to be discharged. The beds are waterproofed by plastic membrane liners (HDPE or PVC) or clay. The water level can be mantained with a height of about 5-10 cm from the bottom of the bed, or otherwise the beds can be totally empty after each feeding pulse.

The sand layer have to be at least 30-40 cm high, with an insulating top layer of gravel and a drainage bottom layer of the same gravel.

The aeration of the bottom layers can be improved connecting the drainage pipes to pipes that rise up the top, in direct contact with atmosphere.

VF beds depth is normally set equal to 0.9-1 meter.

This kind of CW is particularly efficient in nitrification, carbon and suspended solids removal. Due to its prevalently aerobic conditions denitrification is poor.

Free Water Surface (FWS)

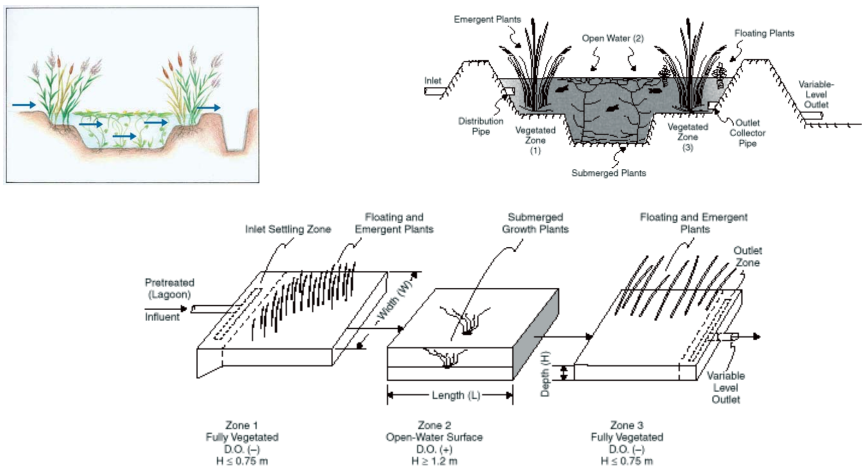


Figure 2-2. Elements of a free water surface (FWS) constructed wetland

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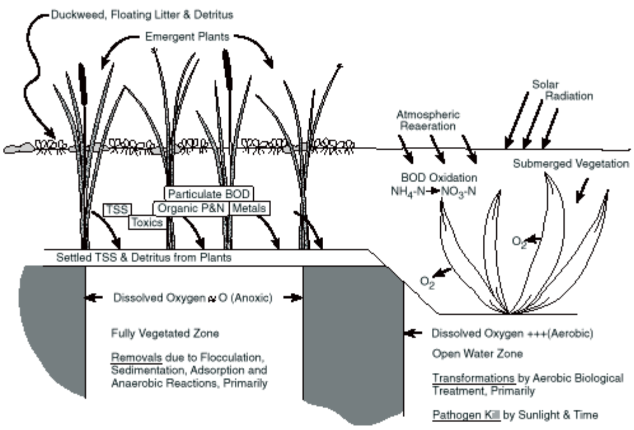
Free water surface (FWS)

Surface flow wetlands are densely vegetated basins, optionally including open water areas, with some sort of subsurface barrier to prevent seepage, soil or another suitable medium to support the emergent vegetation, and water at a relatively shallow depth flowing through the unit. Particulates tend to settle and to be trapped in the system; in such a way they enter into the biogeochemical element cycles within the water column and surface soils of the wetland. At the same time dissolved elements enter the overall mineral cycles of the wetland system.

This kind of Constructed wetlands is particularly efficient in the pathogens removal, due to the high exposure of the wastewater to the UV component of the sunlight. For that reason, and also for a good denitrification power, these systems are often used as tertiary treatment (polishing stage).

Removal mechanisms



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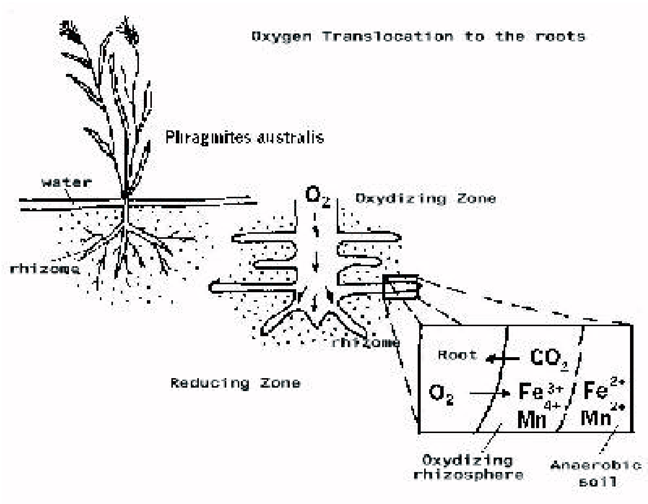
Removal mechanisms

Wetland systems reduce many contaminants, including organics (BOD, COD), suspended solids, nitrogen, phosphorus, trace metals, and pathogens. This reduction may be accomplished by diverse treatment mechanisms such as:

- Sedimentation (Gravitational settling of solids)
- Filtration (Particulates filtered mechanically as water passes through substrate, root masses or fish)
- Adsorption (Interparticle attractive force – van der Waals force)
- Volatilisation (Volatilisation of NH_3 from the wastewater)
- Chemical Precipitation (Formation or co-precipitation with insoluble compounds)
- Chemical Adsorption (Adsorption onto substrate and plant surface)
- Chemical Decomposition (Decomposition or alteration of less stable compounds by phenomena such as UV irradiation, oxidation and reduction)
- Bacterial Metabolism (Removal of colloidal solids and soluble organics by suspended, benthic, and plant supported bacteria. Bacterial nitrification and denitrification)
- Plant Metabolism (Uptake and metabolism of organics by plants. Root excretion may be toxic to organisms of enteric origin)
- Plant Absorption (Under proper conditions significant quantities of Nitrogen, Phosphorus, Heavy Metals or Refractory Organics will be taken up by plants)
- Natural Die-off (Natural decay of organisms in an unfavourable environment)

Role of plants



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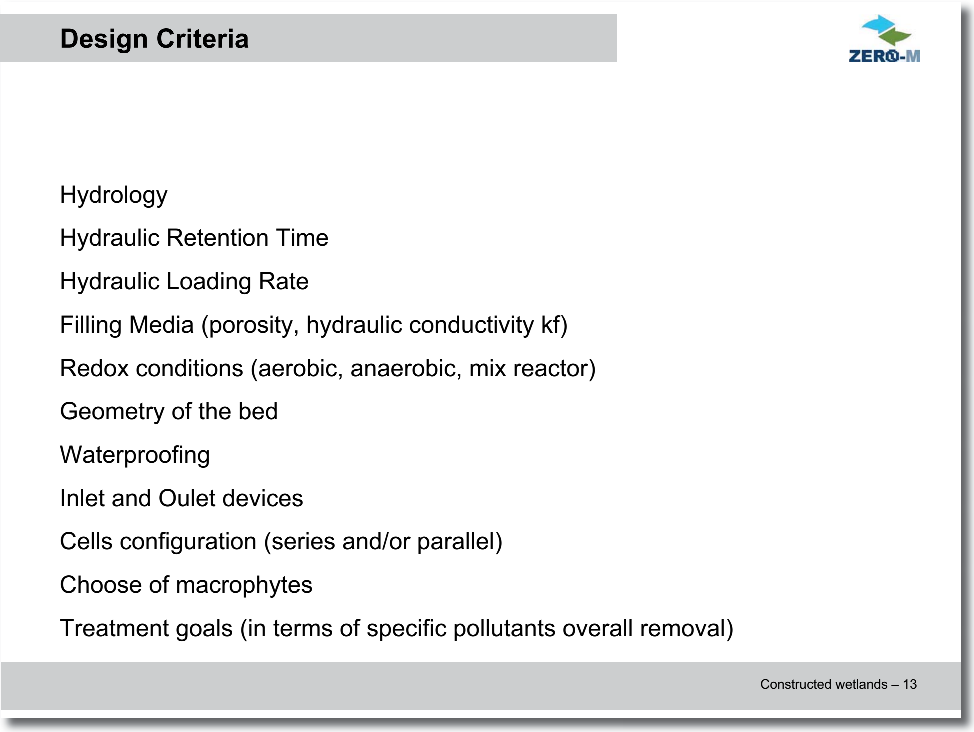
Role of plants

The main role of the aquatic plants (please be sure to select only aquatic plants because of the always water saturated environment that is a fundamental aspect in constructed wetlands) is to act as catalyzers in the purification process. This process, as seen before, is a combination of microbiological, chemical and physical processes. The plants haven't a significant action as direct removal (for some substances, like N and P or organic matter, we can talk of a contribution in the order of 10-20% during the vegetative season); they offer instead a very efficient support for the growth of aerobic bacteria colonies on their rhizomes. Air is pumped towards the root zone by several mechanisms, like convection.

Another important plant's function is the maintenance and continuous re-estabilishment of the hydraulic conductivity inside the beds (preventing that way hydraulic short-cuts that could produce unexpected and undesired HRT decreases).

Amongst all macrophytes, Phragmites australis or communis is the most used worldwide for its optimal performances, for its ability in developing deep roots (0.5-0.7 m), for its resistance to aggressive wastewaters and to diseases.



Design criteria

In designing constructed wetlands, the aim is to maximise contact between the polluted water column and various wetland components, like biofilms, plants, the sediment layer and so on. The efficacy of contact is related to the flow path of water in the system, which in turn is related to both the physical dimensions and the residence time. Most of the constructed wetland specialists warn against the blanket use of simplistic guidelines for all situations. CWs must be individually designed for a particular set of objectives and constraints. Designing CWs for the treatment of pollutants entails:

- sizing for a particular wastewater flowrate, mass loading, and desired removal of a given pollutant
- inlet and outlet structures for water level control, recycling, flow splitting and distribution
- flow path configuration for cells in parallel and/or series
- depth variation within and between cells for habitat diversity, if required, better flow distribution, and pollutant removal
- planting details, including species selection, planting density, range of species
- an operation and maintenance plan

Literature for deepening:
see pdf file CW Manual EPA 1999 on the CD

HF systems sizing

First order kinetic approach – plug-flow reactor

Kadlec&Knight's equation

$$\ln\left(\frac{C_e - C^*}{C_i - C^*}\right) = \frac{-K}{q}$$

$$A_s = \frac{365 \cdot Q}{K} \ln\left(\frac{C_e - C^*}{C_i - C^*}\right)$$

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HF systems sizing

Sizing the beds

Sizing of horizontal flow subsurface systems depends on many parameters that have to be checked out during the preliminary feasibility assessment. After defining the treatments goal and the more appropriate treatment scheme, the sizing procedure can be performed using the well known and scientifically approved methods, like the various first order kinetical equations commonly used (Reed, Kadlec, Kickuth, Cooper) for the pollutants removal and the Darcy law for the hydraulic aspects. As alternative and more simple way it is possible to use "rule of thumb" approaches to the design, based on areal coefficients like "area per p.e." or "area per gramm of COD". The EPA itself, in its last manual for Constructed wetlands for municipal wastewater treatment, advice the use of an Areal Loading Rate as a "conservative" approach to ensure reliable functioning and the respect of fixed concentration limits.

Until now only simple deterministic models can be calibrated for the prevision of performances assuming the horizontal subsurface flow system as a plug-flow reactor and so applying the first-order removal equations. It's well proved that many pollutants decline exponentially to a background concentration (C*) on passage through a water-saturated environment and the net pollutant decrease rate (J) can be expressed by the following equation:

$J = k \cdot (C - C^*)$

The net pollutant removal rate is the mass removal per unit wetland surface area ($g \cdot m^2 \cdot yr^{-1}$), and the kinetic rate constant k is proportional to the amount of active area, such as biofilms, plants and algae, per unit wetland area (IWA STR Nr.8).

Literature for deepening:

IWA Specialist Group on use of Macrophytes in Water Pollution Control: Constructed Wetlands For Pollution Control.- Processes, performance, design and operation. Scientific and Technical Report No. 8; IWA Publishing, London, 2000

Kadlec R.H.; Knight R.L.: Treatment wetlands. Lewis; Boca Raton, 1996

Reed S.C.; Crites R.W.; Mittlebrooks E.J.: Natural systems for waste management and treatment. 2nd Ed. Mc Graw Hill inc.; N.Y. 1995

Vymazal J.; Brix H.; Cooper P.F.; Green M.B.; Haberl R.: Constructed wetlands for wastewater treatment in Europe. Backhuys publ.; Leiden 1998

HF systems sizing

Values of semiempirical constants and background concentrations in the Kadlec's equation

Parameters	BOD_5	SST	NH4-N	NO3-N	TP	FC
K_{20}	180	1000	34	50	12	95
θ	1.00	1.00	1.04	1.09	1.0	1
C^*	3.5+0.053 Ci	7.8+0.063 Ci	0.00	0.00	0.02	10

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HF systems sizing

Previous literature has suggested two different approaches for the definition of the removal rate constant, that can be either area-specific (k: m yr^{-1}) or volume-specific (kv: d^{-1}). Both k and Kv are temperature dependant. The effects of temperature on both the constants can be summerized by the use of a modified Arrhenius equation:

$K_t = K_{20} \cdot \theta^{(T-20)}$

Where

K_t = removal rate constant at T °C

K_{20} = removal rate constant at T=20 °C

θ = temperature correction factor, empirically estimated for available data sets on any single pollutant

The Kinetic constant is then used inside the following equation in order to determine the needed surface area of the HF bed

where

A_s = Superficial area of the bed;

C_e = Outlet concentration, mg/l;

C_i = Inlet concentration, mg/l;

n = porosity (as percentage);

y = mean depth of the water saturated zone;

Q = daily mean hydraulic load (m^3/d).

HF systems sizing

First order kinetic approach – plug-flow reactor

Reed's equation

$$A_s = \frac{Q}{K_T \cdot y \cdot n} \ln\left(\frac{C_i}{C_e}\right)$$

$$K_R \cdot \theta_R^{(T_W - T_R)}$$

HF systems sizing

HF systems sizing

Values of semiempirical constants in the Reed's equation

if $1<T_w<10$

Parameter	BOD_5	NH_4-N	NO_3-N	FC
T_R	20	10	10	20
C*	6	0.20	0.20	-
K_R	1.104	K_{10}	1.000	2.6
θ_R	1.06	1.15	1.15	1.19

if $T_w>10$

Parameter	BOD_5	NH_4-N	NO_3-N	FC
T_R	20	20	20	20
C*	6	0.20	0.20	-
K_R	1.104	K_{NH}	1.000	2.6
θ_R	1.06	1.048	1.15	1.19

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HF systems sizing

HF systems sizing

Rule of thumb – conservative approach

Parameters	Germany ATV	Austria Önorm	Germany IÖV	USA EPA	Czech Republic Vymazal	United Kingdom WRC Cooper	Denmark Brix, Johansen	EC Guidelines CEMAGREF
Surface Area	5 m^2/pe minimum size 20 m^2	6 m^2/pe for BOD	5 m^2/pe		2°: 5 m^2/pe 3°: 1 m^2/pe	2°: 5 m^2/pe 3°:0.5-1 m^2/pe	2 m^2/pe in combination with a second stage VF-RBTS and recirculation	5 m^2/pe for BOD <300mg/l otherwise 10 m^2/pe
Organic Load		11.2 gr BOD/m^2.d		6 gr BOD/m^2.d	8 gr BOD/m^2.d			

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HF systems sizing

Rules of thumb – Conservative approaches

Deriving from the experiences performed in the different countries, often using different construction practices and materials, some national guidelines have been established containing simple recommendations for the sizing of HF systems, as shown in the table.

HF systems sizing

Hydraulic considerations for geometry definition:

Darcy law $Q = K_s A S$

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

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HF systems sizing

Hydraulic requirements

The hydraulic regime of horizontal flow subsurface systems (SFS-h) can be defined by the Darcy law in which the flux depends by the hydraulic conductivity of the filling media and the hydraulic gradient of the system.

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

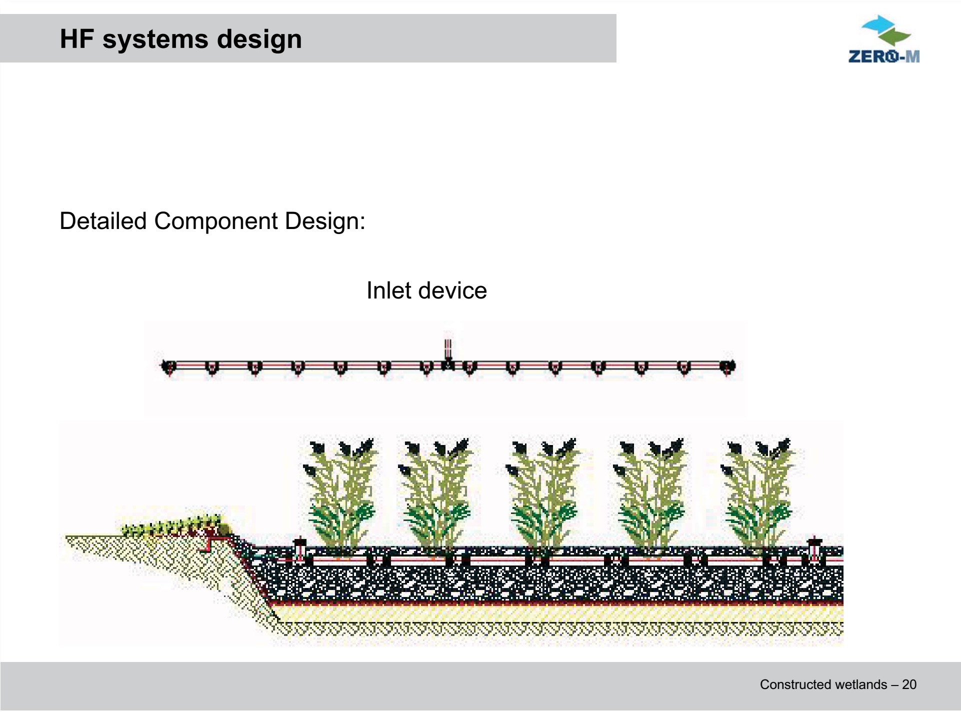
The Darcy equation rules the water flow and level as a function of hydraulic conductivity K_s, cross section W, length of the bed L, slope of the bottom and daily flow Q. Applying the equation to the initial and final height of the bed, H_i and H_f, it's possible to verify if the choosen geometry is appropriate. It's of extreme importance to evaluate the peak flow in respect to tourism facilities fluctuations to be able to choose the right L / W ratio of the beds.

The bed bottom slope is designed in order to respect Darcy's Law and permit to drain the incoming hydraulic load, maintaining the subsurface flow condition in all the possible management scenarios. The bottom's slope ranges from 1% to 5%.

Filling Material

The filter media consists in a combinations of various size gravel. Commonly, the first meter of the bed is filled with coarse rock (average 100 mm diameter) and the remaining part with a fine well cleaned gravel (average 5-10 mm diameter).

The media depth varies, in dependence of the used vegetal essences, from 0,6 m to 0,8 m.



HF systems design

Common goal of feeding systems is to permit an uniform distribution of the wastewater alongs all the bed cross surface. Generally the feeding system is realized by HDPe or PVC pipe parts and fittings, placed in the first meter of the bed (with a coarse filling medium all around). It's usually placed at the same height of the water level, but it can also be set up on the bottom (this choose presents more difficulties in maintenance operations).

T 90° Joints feeding system

This system is realized by HDPe or PVC pipes linked to T 90° joints placed close to themselves with a free manhole to let wastewater out. Feeding system has on every side a screw-plug to permit maintenance operation if clogging occurs (i.e. pumping inside pressurized water). It can be employed on every kind of HF System plant and every climate. If placed 10-15 cm under the top of the bed, the pipes are freeze-protected.

HDPe or PVC pipes are most commonly used. If PVC pipes are used, the feeding system must be realized by fitting the parts with glue. HDPe pipes permits many fitting methods: head-to-head welding is the most commonly used. Another fitting kind is the elettrofusion. Compression fittings are available and are easier to use but more expensive than the others.

Pipe's diameters are depending from previewed hydraulic load: minimal diameter should be 63 mm. Bigger diameters than 160 mm are not generally used.

The distance between feeding's manhole (between every T 90° joint) could be ranged depending of the bed width: commonly it ranges from 0,5 m for smallest beds to 1,5 m for the biggest ones.

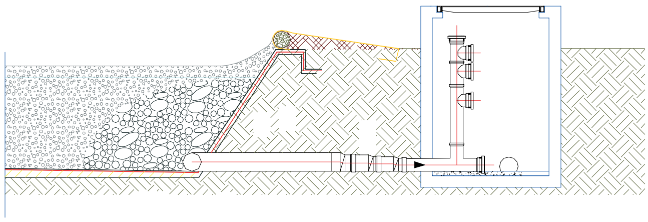
Feeding system's width is generally the same of the bed width. For very large beds (over 15 m) the realization of two or more feeding system units is recommended in order to reach an uniform wastewater distribution.

Pipe's clogging is the main problem that happens. If this problem occurs it is necessary a pressurized water cleaning through a manhole screw-plug placed on each side of the pipe. In the worst case it is necessary to clean directly all the feeding system after removing the coarse filling medium that covers it.

HF systems design

Detailed Component Design:

Oulet device



Constructed wetlands – 21

HF systems design

Vegetation

The medium is typically planted with the same types of emergent macrophyes present in the natural wetlands. The most commonly used macrophyte is Phragmites australis (Reeds) but also Typha spp (cattail) and Scirpus spp. (bulrush) can be easily used.

Waterproofing

The HF System bed is waterproofed by a plastic materials made geomembrane: the most common choice is HDPE. HDPE geomembrane presents the following advantages:

- Total impermeability of the system – that prevents the wastewater infiltration in the ground
- Chemical, solvent and most bacteriological agents resistant
- Roots and rodent resistant
- Non toxic
- Easy to carry and move
- Recyclable materials

Minimal thickness required is depending by the bed size but has to be set equal or greater than 1 mm. Already sized premanifacturated liners are available by factories on demand or available in rolls, and they are normally installed with a double-track welding on place. The HDPE liner should be holded between two TNT liners with 200 gr/m^2 minimal density and placed on flatted and unvenness ground. In the case of sealing with natural soil a Kf <10-7 m/sec is required and a minimum thickness of 30 cm should be given.

Outlet device

The water level has to be always maintained under the filling medium surface: referring to average hydraulic load, the water level will be 5-10 cm under the bed surface. The horizontal flow reed beds outlets include subsurface manifold that should be located just above the bottom of the bed to provide complete control of water level, including flooding and draining. The use of an adjustable outlet is recommended to maintain an adequate hydraulic gradient in the bed and it can also have significant benefits in operating and maintaining the wetland. Adjustable pipes, preregulated pipes or flexible hoses offer a simple control of the water level.

VF systems sizing

Parameters	ATV	Önorm	IÖV	EC Cemagref	Vymazal	WRC Cooper
Area	2.5 m2/pe min. value 10 m^2	5 m^2/pe for BOD	2-4 m2/pe		2°: under 100 pe: 1st bed 0,8-2 m^2/pe 2nd bed 50-60% of the 1st bed size 1 m^2/pe for BOD 2-5 m^2/pe for BOD+N 3°: 41-2 m^2/pe	2°: 1 m^2/pe for BOD 2°: 2 m^2/pe for BOD+N under 100 pe: 1st bed: $3.5P^{0.35}+0.6P$ 2nd bed: 50% of the 1st bed size P=population equivalent Range 2-4 m^2/pe; 0.78 m^2/pe for 100 pe
Hydraulic Loading Rate (HLR)	60 mm/d		30-60 mm/d	30 mm/d	20-80 mm/d	
Organic Loading Rate (OLR)			10-20g BOD/m^2*g			

Constructed wetlands – 22

VF systems sizing

Sizing procedure for VF beds is mainly based on the nitrification process; in fact, when the treatment goals normally required for ammonium concentration are fulfilled, all the other parameters are satisfactory eliminated too.

A common practice for dimensioning VF reed beds is to calculate an area coefficient per person equivalent. There are guidelines available in several countries. They work with theoretical inlet concentrations and loads and treatment goals that are defined by the particular national requirements. Usually they work well for small plants with domestic wastewater. It is very important to proof the applicability of these income and outcome values from case to case.

VF systems sizing

Organic Loading Rate = 20 g COD/m^2.d with a maximum TSS concentration of 100 mg/l

TSS Loading Rate = 5 g/m^2.d

Hydraulic Loading Rate = <80 mm/d in winter and 120 mm/d in summer

Constructed wetlands – 23

VF systems sizing

Clogging prevention

One upper limit for the performance of VF beds is the formation of clogging phenomena on the surface. Soil clogging appears when the conductivity of the filter media is reduced. Following the increase of biomass and development of biofilms and microorganisms leads to a strong reduction of oxygen presence in the lower layer and consequently to a decrease in efficiency yields for all the oxidising processes (nitrification, carbon oxidation, pathogen removal). Concerning the causes for the reduction of the conductivity of the filter media some empirical values for upper inlet concentrations and loads were found which can be used as dimensioning tool. German experiences have shown that good performances of VF reed beds dimensioned according the German guidelines (ATV 262) can be achieved in a long term period using the two following empirical values:

- Organic Loading Rate = 20 g COD/$m^2 \cdot$d with a maximum TSS concentration of 100 mg/l
- TSS Loading Rate = 5 g/$m^2 \cdot$d
- Hydraulic Loading Rate = < 80 mm/d in winter and 120 mm/d in summer (Geller &Höhner, p. 35)

VF systems sizing

OI d + OI c - OD > 0 (gr/g)

OD = Oxygen Demand = 0,85 x (BODin – BODout) [g/d] + 4,3 x (TKNin – TKNout) [g/d] + 0,1 x 2,9 x (TKNin – TKNout) [g/d]

As = (OD / Ka) x 1.25

Constructed wetlands – 24

VF systems sizing

Calculation of Oxygen Demand

Another approach for the sizing is to calculate the necessary area demand by verifying the oxygen availability within the filter in respect to the oxygen demand.

Since Nitrification is an oxygen consuming process, the following oxygen balance has to be respected:

OI·d + OI·c - OD > 0 (gr/g)

where:

OI·d·(g O_2/day) = input of oxygen to the system by diffusion = 1·[g·O_2·h^{-1} m^{-2}] x Surface of the bed [m^2] x (24 [h] – 1,5 [h] x number of daily feedings)

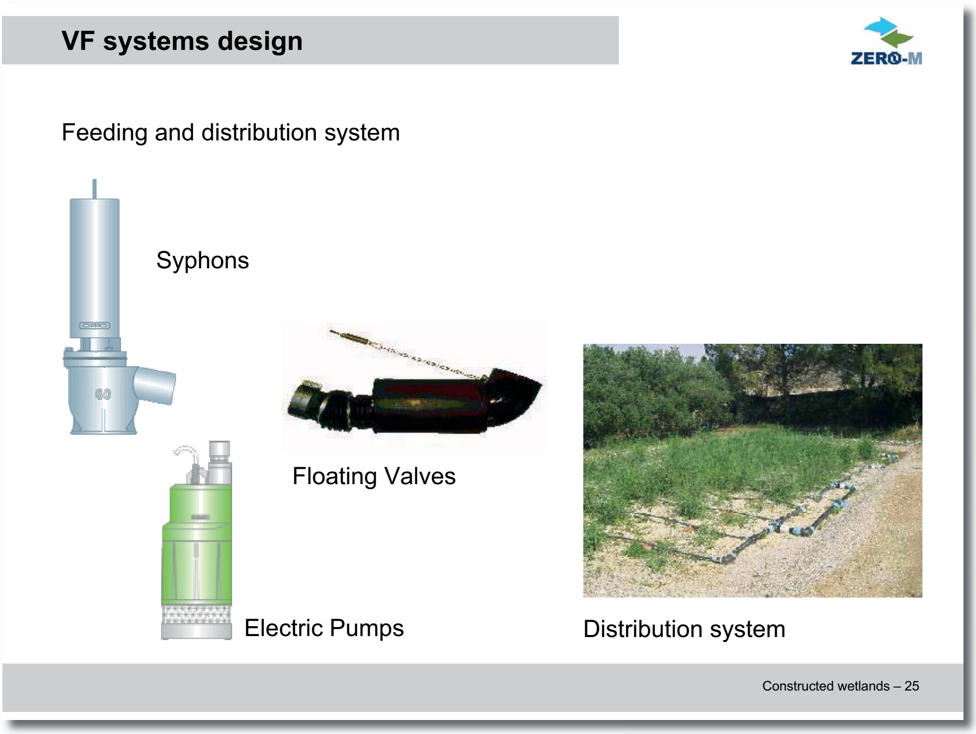
OI·c·(g·O_2/day) = input of oxygen to the system by convection = 0,3 [g·O_2·l^{-1}] x Qd [m^3/d] x 1000 [l/m^3]

OD = Oxygen Demand = 0,85 x (BOD_{in} – BOD_{out}) [g/d] + 4,3 x (TKN_{in} – TKN_{out}) [g/d] + 0,1 x 2,9 x (TKN_{in} – TKN_{out}) [g/d]. (Platzer 1998)

As = OD/Ka where Ka is an empirical aeration coefficient assumed in the range 30-56 gr O_2/m^2·d

Special ways of VF construction

In Norway the vertical beds are socalled Pre Filters, covered to keep the temperature. The French VF construction (Cemagref) is working without special pre treatment. In the UK the VF reeb beds are assembled in series (multistage) and the beds consist of a several layers of filter substrate (multilayer).



VF systems design

Intermittent feeding system

Through intermittent feeding the pre-treated wastewater can be charged to the filter area in intervals. The wastewater is distributed above the whole surface through perforated pipes.

Depending on the terrain different options are given: the presence of a difference in height between the pre-treated wastewater and the vertical filter bed allows the utilization of mechanical devices without (using electric, fossil or solar) energy.

The intermittent feeding device could be switched either quantity or time related, or both. Usually a quantity related feeding is applied.

Systems without energy:

- Valve/Siphon (Rohrventil)
- Tipping bucket
- Saugheber (Phytofilt)

Electric systems:

- Pump
- Electric slide

Distribution system

An even distribution of the wastewater on the whole surface has to be achieved. This is dependant on the cross section of the pipes, the distance of pipes, the distance of holes and the feeding quantity per interval. The feeding system should be situated above the surface to be accessible for maintenance works.

VF systems design

Filling media

Parameters	Germany ATV	Austria Önorm	Germany IÖV	UK Crites Tchob.	Czech Republic Vymazal	United Kingdom WRC Cooper	Denmark Brix, Johansen	EC Guidelines CEMAGREF
Filling material (Substrate)	Sand or fine gravel U=d60/d10 <5	Gravel Inlet: 16/32 (4/8) Bed: 4/8 (2/4)		Gravel: Inlet: 50 mm Bed: 3-32 mm	Washed Gravel: 3-16 mm	Washed Gravel: 3-6 mm 5-10 mm 6-12 mm	U=d60/d10 <5 d10 > 0.3 mm	Washed Gravel: 3-6 mm 5-10 mm 6-12 mm
Permeability	Kf 10^{-4}–10^{-3} m/s				Kf 10^{-3} - $3*10^{-3}$ m/s	Kf 10^{-3} m/s	Kf $1*10^{-3}$ m/s	Kf $1*10^{-3}$ m/s to$3*10^{-3}$

Constructed wetlands – 26

VF systems design

Sealing of the planted filter

Bottom and sidewalls of the filter bed have to be waterproof, if a contamination of the groundwater can be expected. In the case of sealing with natural soil a Kf <10-7 m/sec is required and a minimum thickness of 30 cm should be given.

Artificial sealing with impermeable layer: The material should be acid-resistant and alkali proof, frost-resistant, roots and rodent resistant, non toxic, easy to carry and move, made of recyclable materials (preferred material: HDPE or LDPE).

If no special sealing has been installed in the beds there must be a possibility to take a sample of the treated wastewater before it leaves the filter bed.

Filter media

The main filter layer consists of washed sand of selected size. An effective grain size of d10 > 0,2 mm and a uniformity factor U (d60/d10)< 5 and a Kf 10-4 to 10-3 m/s are recommended reference numbers.

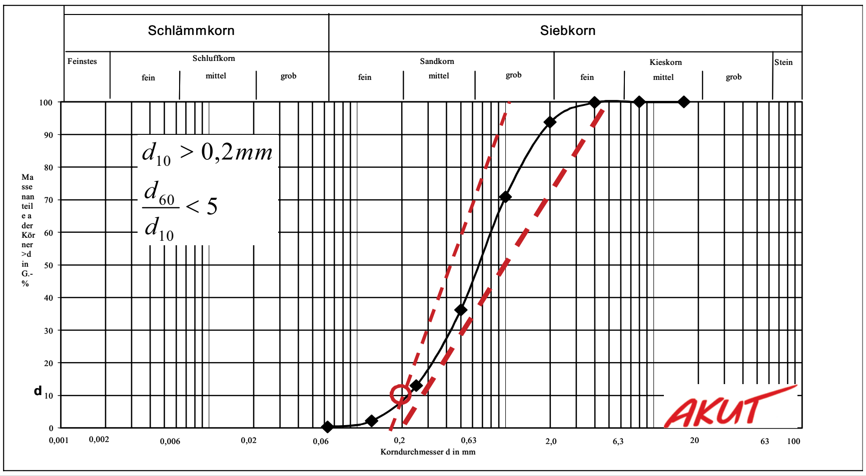
The drainage can be achieved either with drainage pipes and/or with coarse gravel. In cold climate a shallow gravel cover upon the main sand layer is recommended.

Vegetation

The filter beds are usually planted with the same types of emergent macrophytes as present in the natural wetlands. Most common is Phragmites australis (reeds) but also Typha ssp. (cattail) and Scirpus ssp. (bulrush) can be used.

VF systems design

Filling media



Source: German guidelines ATV (graph by Akut)

Constructed wetlands – 27

VF systems design

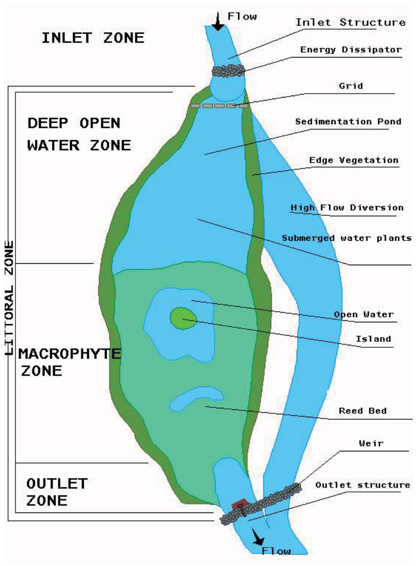
Literature for deepening:

Abwassertechnische Vereinigung (ATV): Grundsätze für Bemessung, Bau und Betrieb von Pflanzenbeeten für kommunales Abwasser bei Ausbaugrößen bis 1000 EW. Arbeitsblatt A 262; Hennef, 1998

Österreichisches Normungsinstitut (ON): Bepflanzte Bodenfilter (Pflanzenkläranlagen) – Anwendung, Bemessung, Bau und Betrieb. ÖNORM B 2505; Wien: 16, 1997

FWS Design

An example of design for a FWS



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FWS design

Sizing of the Free Water Surface system is calculated using the basic plug-flow equation as suggested by Reed, Crites and Middlebrooks (1996):

$$C_e/C_i = \exp(-Kt \cdot t)$$

where:

C_i = outlet concentration of pollutant (mg/l)

C_e = inlet concentration of pollutant (mg/l)

KT = constant temperature dependant (d-l)

t = hydraulic retention time (d)

$$A = Q\,(\ln C_i/C_e) / Kt \cdot d \cdot n$$

where:

A = Superficial area of the constructed wetland (m^2)

C_i = outlet concentration of pollutant (mg/l)

C_e = inlet concentration of pollutant (mg/l)

Q = average water daily flow (m^3/d)

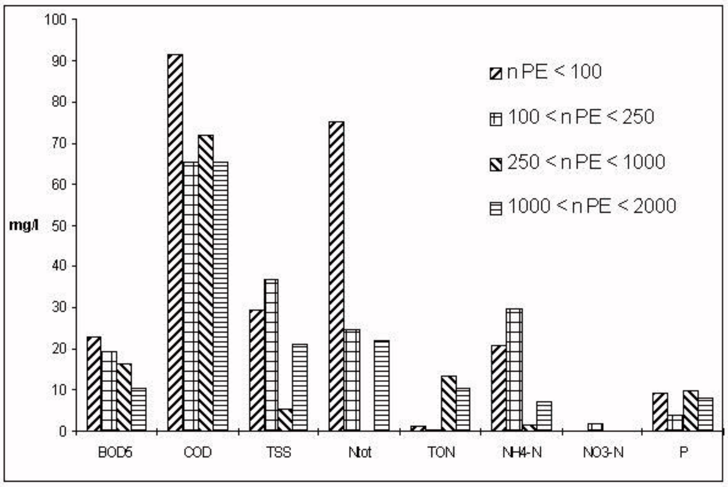
d = average depth of water in the FWS system (m)

n = porosity of filling materials (commonly used 0.75 for FWS)

Investigations about pathogen removal in free water systems showed that the total elimination increases when the whole area is divided into several single units instead of one.

Performances

Mean outlet values on 213 european HF CWs for secondary treatment



Constructed wetlands – 29

Performances

Link:

http://firehole.humboldt.edu/wetland/twdb.html

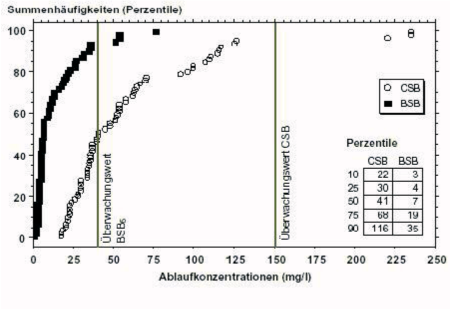
Constructed Treatment Wetland System Description and Performance Database.This web site serves as a access point to a database on constructed treatment wetlands. The treatment wetland database (TWDB) contains system descriptions and performance data for a large number of pilot, and full-scale wetland systems treating a variety of sources, including municipal wastewater, stormwater run-off, industrial wastewater, and agricultural runoff. The database contains the bulk of the entries in the revised EPA sponsored North American Database (NADB Version 2), and data from many additional treatment wetlands. While the emphasis is on constructed wetlands, natural wetlands are also included in the database.

http://www.swamp-eu.org

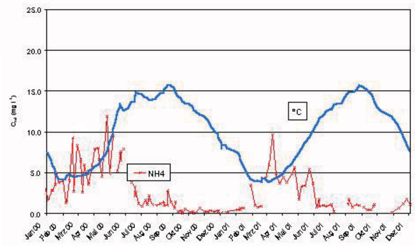
Several sets of data of Constructed Wetlands (HF, VF and Hybrid systems) realised in different touristic facilities in Austria, Germany, Italy, Latvia and Lithuania.

Performances

Mean outlet values on 62 german VF CWs for secondary treatment < 50 pe



Typical annual pattern of NH4-N output concentration of a VF system under German climatic conditions (Wiedersberg, Sax. at 400 m altitude)



Performances

Literature for deepening:

Geller, G.; Höner, G.: *Anwenderhandbuch Bewachsene Bodenfilter mit CD-Rom - Evaluation von bewachsenen Bodenfiltern im deutschsprachigen Raum und Hinweise zum Qualitätsmanagement.* AZ 14178-09; Ingenieur-büro Ökolog Geller und Partner, Augsburg; Report AZ 14178-01, Deutsche Bundesstiftung Umwelt 2002