# Constructed Wetlands for the Treatment of raw Wastewater: the French Experience

***This paper describes the experiences with the French CW system for treating raw wastewater.***

Authors: Stephane Troesch, Dirk Esser


## Abstract

Vertical Flow Constructed Wetlands for small communities (< 5000 people equivalent) have been successfully developed in France since the 1990's. This paper summarizes the results and performances of 70 plants designed and built by Epur Nature or SINT. The results show clearly that the design perform well for organic matter removal and nitrification and make easy the sludge management. Therefore if well designed, such systems can achieve an outlet quality of $BOD_5$ < 20 mg/L, COD < 90 mg/L, SS < 30 mg/L and TKN < 15 mg/L. Besides, in order to reduce global footprint a new vertical flow configuration, patented by Epur Nature, is presented.


## Introduction

Among the different constructed wetlands systems treating domestic wastewater, a two stage Vertical Flow (VF) Constructed Wetland (CW) is the most common design developed in France.

The originality of this "French System" is that it accepts raw sewage directly onto the first stage and treats the primary sludge on the surface of the first stage beds. This greatly facilitates sludge management as compared to systems which need to deal with primary sludge. The use of this system, developed by the CEMAGREF (now IRSTEA) in the early 1980's (Liénard, 1987), really took off when it was developed by SINT in the 1990's under the brand name Phragmifilter®. Indeed, if we add to the easier sludge management the good performances obtained for SS, COD and nitrification (Molle et al., 2005) and the low operation costs, it is easy to understand the choice that small communities (less than 5000 PE) in France have made and are still making. "French systems" have also been recently build in Switzerland, Germany, Belgium, Spain, Portugal, Italy and more and more other countries, but they have not achieved there yet the "Number 1" position this technology has gained today as the most popular system for treating system for waste water streams from rural communities in France.

An estimated 2000 to 2500 CWs treating raw sewage exist today in France, for capacities of 20 to 6000 PE (Figure 1). Roughly a third of these plants (around 800) have been designed or designed and build by SINT or Epur Nature or companies associated with them. Figure 2 shows the plant in Roussillon in the south of France which is designed for 1250 PE.

## Key factors:

- Two-stage vertical flow constructed wetlands for treating raw wastewater have been introduced in France and successfully applied (currently > 2000 plants are in operation).
- Each stage of the integrated sludge and wastewater treatment wetland has parallel operated filter beds: under normal conditions 3 beds in the first stage and 2 beds at the second stage.
- Each bed of the first stage receives the full organic load during the feeding phase, which usually lasts 3 to 4 days, before being rested for twice this amount of time.
- The specific surface area requirement for the system has been found to be 1.2 m² per people equivalent (PE) for the first and 0.8 m² per PE for the second stage, resulting in an area requirement of 2 m² per PE for the whole system.
- The treated sludge from the first stage has to be removed every 10 to 15 years and is usually directly valorised by land spreading.
- During the last years, a deep single-stage vertical flow bed that comprises both stages into one has been developed with the aim to reduce the footprint. The Bi-filtre® system has a footprint of 1.5 m²/PE.

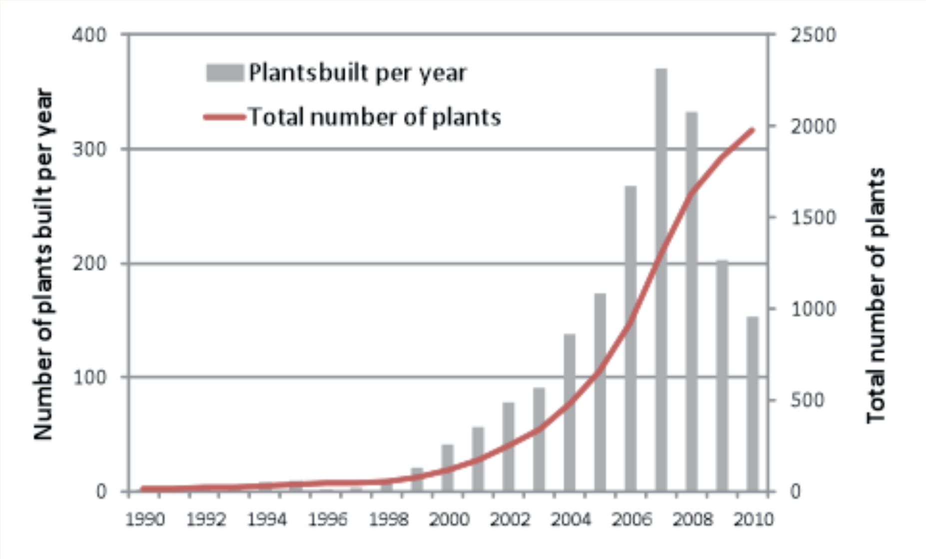


Figure 1: Development of vertical flow CW over time in France (French Ministry data base)

Figure 2: Roussillon plant, France (1250 PE, Epur Nature)

## Design and Results

### Design

The sizing of VF CWs is still roughly based on organic load acceptance (in terms of active surface area per people equivalent [PE] - one people equivalent (PE) is defined in France as the following production of pollutants: 150L/PE/d, 90 g SS/PE/d (combined sewer) or 60 g SS/PE/d (separate sewer), 120 g COD/PE/d, 60 g $BOD_5$/PE/d, 15 g TKN/PE/d and 2.2 g TP/PE/d). Current recommendations are 2 stages of filters with a total active area of 2m²/PE. While the first stage is divided into 3 identical filters, the second is divided into identical two filters. Filter configuration and media profile are presented in Figure 3 and Figure 4.

After a coarse screening (30 mm) of the raw sewage wastewater the influent is transferred onto the first stage. Each primary stage unit receives the full organic load during the feeding phase which lasts 3.5 days, before being rested for 7 days. These alternating phases of feeding and rest are fundamental in controlling the growth of the attached biomass on the filter media (avoid biological clogging), to maintain aerobic conditions within the filter and to mineralize the sludge deposit accumulated on the surface. The role of the first stage is to

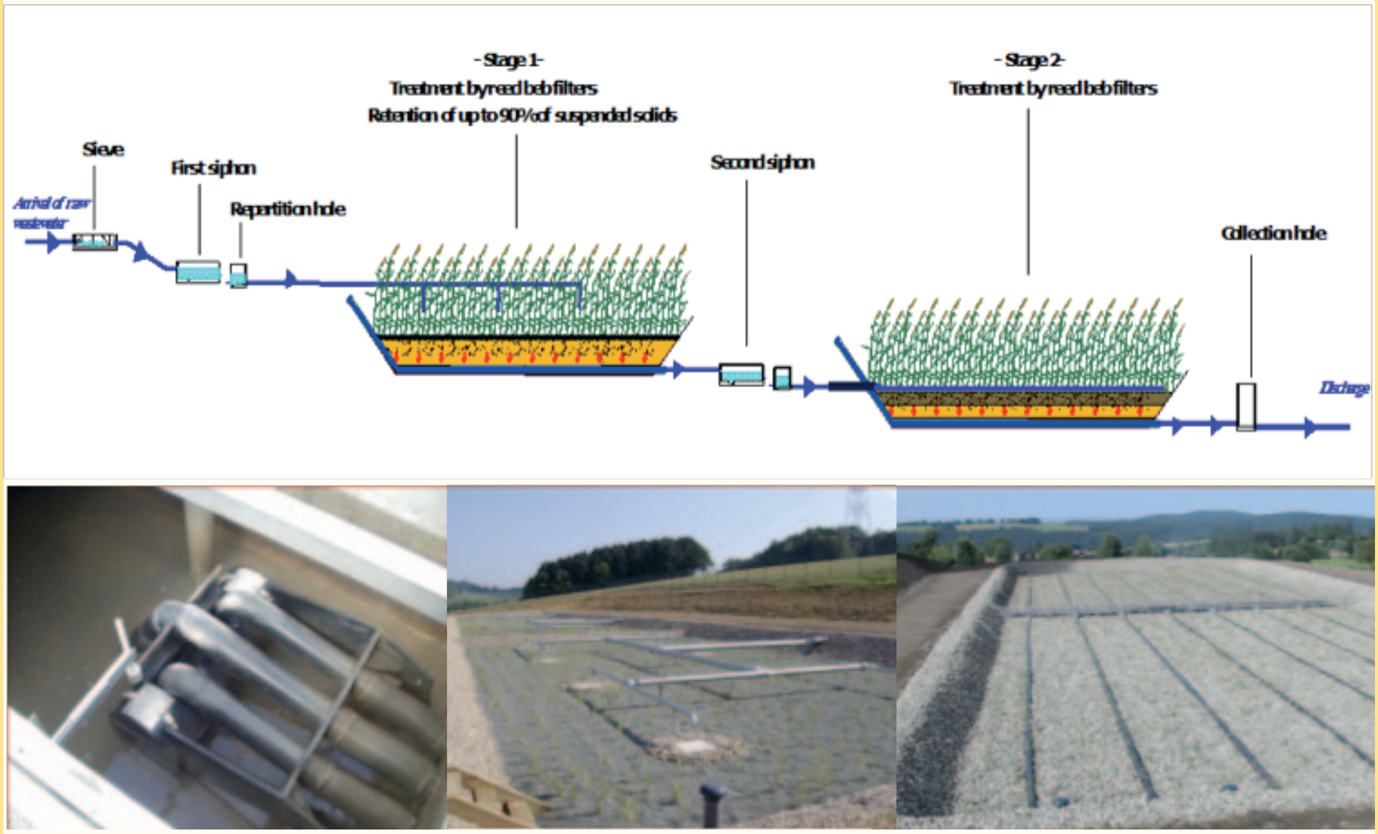


Figure 3: VF CW configuration with siphon

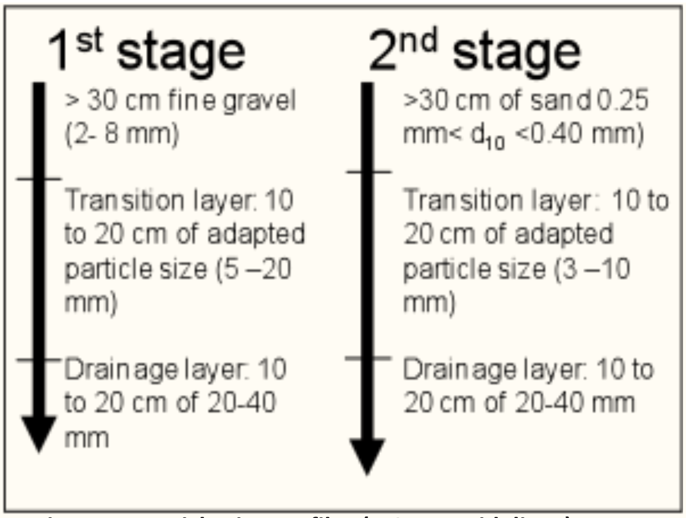


**Figure 4: Particle size profiles (IRSTEA guidelines)**

**Figure 5: Putting in filtering materials on the 1st stage (Epur Nature)**

retain suspended solids and have a secondary treatment of the dissolved organic pollutants. The effluent is then sent to the second stage for further treatment of organic pollutants and in particular nitrification.

The surface recommended per stage can be adapted according the level of pollutant removal required by the water authorities and the hydraulic load (HL) especially for combined sewers or clear water intrusion into the sewerage network.

The French guidelines give a minimum total area of 2 m² PE with a first stage of 1.2 m²/PE divided in 3 identical alternately fed units (i.e. an organic load of about 300 g COD/m²/d and a hydraulic load of 0.37 m/d on the filter under operation), and a second stage of 0.8 m²/PE divided over 2 identical alternately fed units. Organic loading is generally limiting as a hydraulic load of up to 300 L/PE can be accepted (thus a dilution with clear water of 100 % can be accepted and in practice we have designed to accept up to 0.9 m dry weather flow on the filter in operation). Pollutant loading can be doubled during the summer months in France, which make them particularly interesting for tourist facilities, as long as the hydraulic load on the filter in operation does not exceed 0.66 m/d for dry weather flow and as long as enhanced nitrification is not required (Boutin et al., 2010). When the accumulate sludge layer on the first stage exceeds 10 cm, it is recommended that the maximum hydraulic load should not exceed a 0.9 m/d during frequent rain events (once a week) and 1.8 m/d during less frequent rain events (once a month) on the filter in operation (Molle et al., 2006).

Wastewater is fed on the filter surface by batches (by storage and high capacity feeding system) to ensure an optimum distribution of water over the whole filter surface. When the difference in height between the

**Figure 6: First stage feeding device (Epur Nature)**

**Figure 7: Second stage feeding device (Epur Nature)**

**Table 1: Characteristics of the data base plants (70 units, SINT/Epur Nature database)**

| Age of the Plant (years of operation) | | | Hydraulic load | | | Organic load | | |
|---|---|---|---|---|---|---|---|---|
| ≤ 3 | 3 < age < 6 | > 6 | 50 % < | 50 % < 100 % | >100 % | < 50 % | 50 % < 100 % | > 100 % |
| 54 % | 40 % | 6 % | 43% | 43% | 14% | 52% | 41 % | 7 % |

**Table 2: Inlet/outlet concentrations and removal efficiencies of a two stage VF CWs (SINT/Epur Nature database)**

| | Inlet concentration (mg/L) | | Outlet concentration (mg/L) | | Removal efficiencies (%) | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| COD | 651 | 282 | 50 | 29 | 92 | 7 |
| $BOD_5$ | 291 | 140 | 8 | 9 | 97 | 3 |
| SS | 242 | 133 | 8 | 6 | 97 | 3 |
| TKN | 56 | 34 | 7 | 12 | 90 | 12 |
| TP | 7 | 4 | 6 | 3 | 32 | 25 |

inlet and the outlet is sufficient, it is possible to work without energy by using a siphon (e.g. Aquasaf siphon, Figure 2) as feeding device. The water distribution onto each stage has a fundamental importance; therefore it is recommended to design i) the feeding system for the first stage to deliver a flow of 0.5 $m^3$/h per square meter of fed bed surface, with one feeding point for a maximum of 50 m² and ii) the feeding system of the second stage to deliver 0.25 $m^3$/h to 0.5 $m^3$/ per square meter, according to the characteristics of the sand, with one feeding point for 1 m² of filter surface (Figure 6 and Figure 7).

Concerning the sludge management, with an accumulation rate of 1 to 2 cm/year, a free board of 50 cm on the first stage ensures its accumulation for about 10 years before emptying.

**Global Efficiencies**

<u>Pollutant Removal efficiencies</u>

The global removal efficiencies were assessed on constructed wetlands following the French design for domestic raw wastewater and were based on a statistical treatment of a data base of 70 plants built by SINT or Epur Nature. The plants characteristics (age, organic and hydraulic load) of these plants are summarized in Table 1. They all are 2 stages VFCW (with a 2 m²/PE design) with 0.4-0.6 m of gravel (2-8 mm) on the first stage and 0.3 to 0.4 m of sand (0-4 mm) on the second stage, fed with raw wastewater

Table 2 shows the inlet/outlet concentrations and the global removal efficiency for plants with a hydraulic load lower than 0.9 m/d on the filter in operation on the first stage. The influent is quite variable mainly due to the different characteristics of sewerage networks (combined or separate and amount of clear water intrusion). Globally the system is able to achieve a good effluent quality for all parameters except phosphorous (P-removal is mainly correlated to the phosphate adsorption capacity of the filtering materials and not long-lasting) and denitrification (due to the prevailing aerobic conditions in the filters).

Removal efficiencies of organic pollutants are fairly constant, (low standard deviation [SD]) while the nitrification rate (assumed as the TKN removal) shows a 12 % standard deviation and, not surprisingly, SD for phosphorus is even higher. Varying nitrification rates are caused by differences between filter materials and also are correlated to the hydraulic and organic loads.
Finally, the statistical data treatment showed that there is no significant impact of the season on the removal rate of the assessed parameters.

<u>First stage of treatment</u>

The results observed on the first stage are summarized in Table 3. We can clearly observe that the first stage of treatment concerns mainly SS, COD and BOD5 removal, although nitrification is not negligible with a mean of 60 % of TKN removal. The removal efficiency of the first stage is enhanced by the sludge layer deposit which regulates the infiltration and the hydraulics of the filter.

As observed in Figure 8 which presents the removal performances in relation the applied load (100 % removal represented by the dotted line) the first stage removal efficiencies for COD and SS are linear, even for loads above 300 g COD/m²/d on the filter in operation, without clogging. On the other hand, nitrification removal decreases rapidly with an increasing load as showed on Figure 9. This is the result of a higher oxygen demand induced by concomitant higher organic loads and lower oxygenation rates due to higher hydraulic loads.

**Table 3: Inlet/outlet concentrations and removal efficiencies of the first and second stage of treatment respectively (SINT/ Epur Nature database)**

| | 1st stage | | | | 2nd stage | | | |
|---|---|---|---|---|---|---|---|---|
| | Outlet conc. | | Removal efficiencies | | Outlet conc. | | Removal efficiencies | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| **SOB** | 127 | 77 | 79% | 13 | 50 | 29 | 56% | 23 |
| **$BOD_5$** | 36 | 32 | 86% | 13 | 8 | 9 | 72% | 21 |
| **SS** | 32 | 20 | 85% | 10 | 8 | 6 | 72% | 35 |
| **TKN** | 20 | 15 | 59% | 21 | 7 | 12 | 71% | 19 |

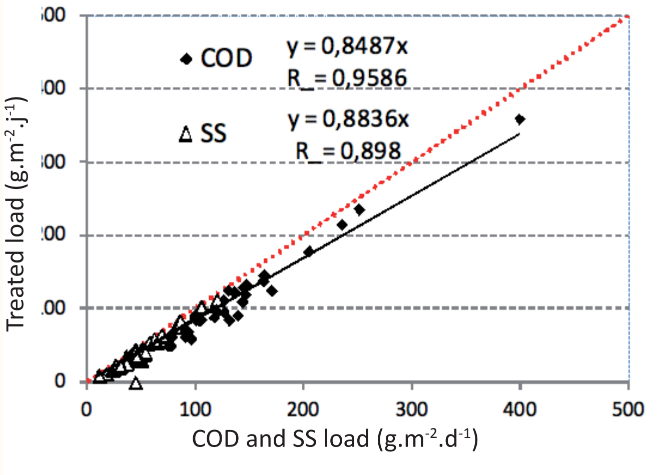


**Figure 8: Treated COD and SS on the first stage for 0.1 < HL <1.57 m/d.**

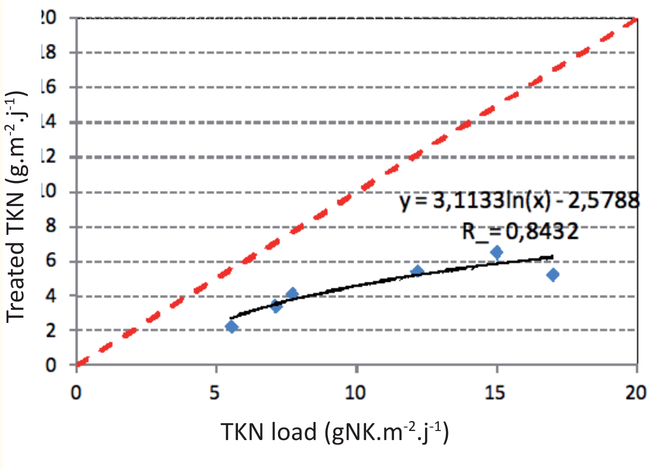


**Figure 9: Treated TKN on the first stage for 0.1 < HL <1.57 m/d.**

Second stage of treatment

The results presented in Table 3 show that the second stage mainly contributes to nitrification while this stage has a polishing effect for organic pollutants because of the low inlet concentrations (= outflow of the first stage) for these parameters.

Figure 10 and Figure 11 show that as for the first stage, the removal rates for COD and SS are quite constant with increasing loads whereas TKN removal is affected by load above 15 g TKN/m²/d.

Sludge accumulation and handling

During its storage on the first stage, sludge is continuously dewatered and mineralized through aerobic processes by micro- and macro-organisms under optimal hygrometric conditions during the rest period. The final sludge quality on plants where sludge has already been removed after 10 to 15 years of accumulation shows dry matter (DM) content of 25-30% and a organic matter content of about 40% of DM. This indicates that approximately 60% of organic suspended solids loaded have been mineralized. Moreover its

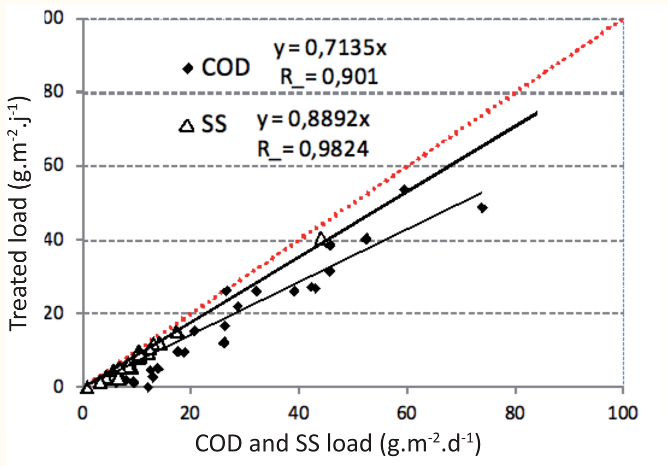


**Figure 10: Treated COD and SS on the second stage 0.1 < HL <1.57 m/d.**

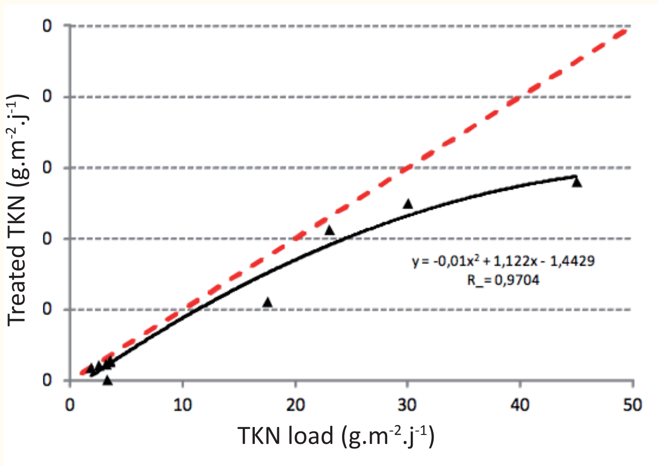


**Figure 11: Treated TKN on the second stage 0.1 < HL <1.57 m/d.**

**Figure 12: Sludge removal of the first stage (Roussillon, France) after 14 years of operation**

compost-like appearance makes this stabilized sludge an interesting material for land spreading as long as no contamination (cooper from vineyards treatment for example) has been brought in with the wastewater. Figure 12 shows the removal of the sludge from the first stage of the Roussillon plant after 14 years of operation.

## A French configuration with reduced footprint

During the last years, SINT and Epur Nature developed the approach further by introducing a deep single-stage vertical flow bed that comprises both stages into one in the aim to reduce the footprint.

This process, patented by Epur Nature as Bi-filtre®, consists of two piled-up vertical stages (Figure 13). While classical systems in France are designed with 2 m²/PE (1.2 m² and 0.8 m² on the first and second stage, respectively), the Bi-filtre® has a larger total filtration area with 2.5 m²/PE (1.5 m² and 1 m² on the first upper and second lower stage, respectively) but a foot print reduced to 1.5 m²/PE. To favour aeration of the system, an intermediate natural aeration system is introduced at the interface between the first and second stage.

The results obtained from 50 full scale Bi-filtres® show that such systems, if well designed, can guarantee an outlet quality of 35 mg/L in SS, 125 mg/L in COD, 25 mg/L in BOD and 20 mg/L in KN with a total foot print of 1.5 m²/PE.

## Conclusion - Outlook

As shown in this paper, the French design with a 2 m² PE design is able to guarantee high removal efficiencies and is well adapted for rural communities (< 5000 PE) even with highly variable loads (organic and hydraulic). The system has high removal on carbon and nitrification, but, in its classical configuration is not adapted for total nitrogen and phosphorus treatment. Therefore specific configurations have been developed mixing vertical flow with subsurface horizontal flow (with and without recirculation) or combining VF CW with waste stabilization pond for total nitrogen removal (e.g. Figure 14), and/or using specific active filter materials for a phosphorous removal.

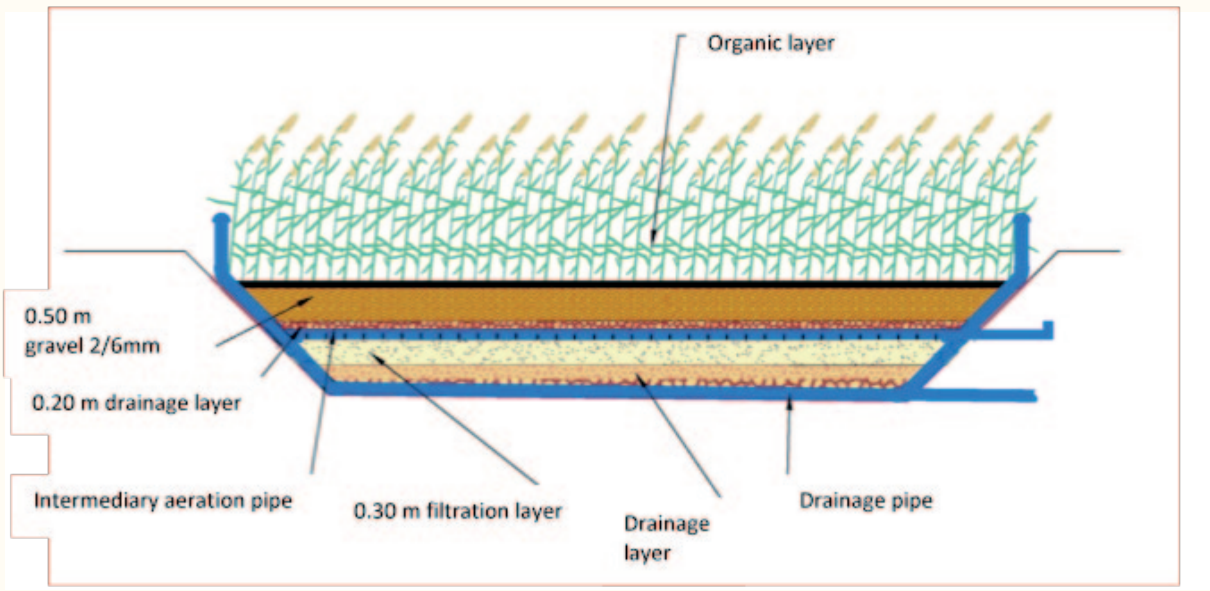


**Figure 13: Cross section of a Bi-filtre®**

**Figure 14: Saint Etienne de Tulmont, France (1900 PE, Epur Nature)**

**References**


Boutin, C., Prost-Boucle, S., Boucher, M. (2010): Robustness of vertical Reed Bed Filters facing loads variations: the particular case of campsites. In: Masi, F., Nivala, J. (eds.): Proceedings of the 12th IWA Specialized Group Conference on „Wetland Systems for Water Pollution Control“, 3-8 October 2010, San Servolo, Venice, Italy, pp.177-185 (ISBN 978-88-6060-300-5).

Liénard, A. (1987): Domestic wastewater treatment in tanks with emergent hydrophytes: latest results of a recent plant in France. Water Sci Technol 19(12), 373–375.

Molle, P., Liénard, A., Boutin, C.; Merlin, G., Iwema, A. (2005). How to treat raw sewage with constructed wetlands: an overview of the french systems. Water Sci Technol 51(9), 11-21.

Molle, P., Liénard, A., Grasmick, A., Iwema, A. (2006). Effect of reeds and feeding operations on hydraulic behavior of vertical flow constructed wetlands under hydraulic overloads. Water Res 40(3), 606-612.



**Names:** Stephane Troesch

**Organisation**: Epur Nature, ZAC des Balarucs

**Town, Country:** Caumont-sur-Durance, France

**eMail**: stephane.troesch@epurnature.fr

**Names:** Dirk Esser

**Organisation**: SINT (Société d‘Ingénierie Nature & Technique)

**Town, Country:** La Chapelle du Mont du Chat, France

**eMail**: dirk.esser@sint.fr