Sustainable Sanitation

Practice

EcoSan Club

Issue 12, 07/2012

- Treatment Wetlands in Austria
- The „French System“ for Treating Raw Wastewater
- Experiences of Constructed Wetlands in Uganda
- Small Community Wastewater Treatment and Agricultural Reuse, Marocco
- CWs for Urban Wastewater Treatment in Egypt
- Sludge Treatment in Reed Beds Systems

Treatment wetlands

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Sustainable Sanitation Practice (SSP) aims to make available high quality information on practical experiences with sustainable sanitation systems. For SSP a sanitation system is sustainable when it is not only economically viable, socially acceptable and technically and institutionally appropriate, but it should also protect the environment and the natural resources. SSP is therefore fully in line with SuSanA, the Sustainable Sanitation Alliance (www.susana.org). • SSP targets people that are interested in sustainable sanitation systems and the practical approach to it. • Articles are published after blind review only. • Sustainable Sanitation Practice is published quarterly. It is available for free on www.ecosan.at/ssp.

Sustainable Sanitation Practice (SSP) hat zum Ziel praxisrelevante Information in hoher Qualität im Zusammenhang mit „sustainable sanitation“ bereit zu stellen. „sustainable“ also nachhaltig ist ein Sanitärsystem für SSP wenn es wirtschaftlich machbar, soziokulturell akzeptiert, technisch als auch institutionell angemessen ist und die Umwelt und deren Ressourcen schützt. Diese Ansicht harmoniert mit SuSanA, the Sustainable Sanitation Alliance (www.susana.org). • SSP richtet sich an Personen, die sich für die praktische Umsetzung von „sustainable sanitation“ interessieren. • Artikel werden nur nach einer Begutachtung veröffentlicht. • Sustainable Sanitation Practice erschient vierteljährlich, kostenlos unter: www.ecosan.at/ssp.

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Publisher: EcoSan Club, Schopenhauerstr. 15/8, A-1180 Vienna, Austria • chairperson: Günter Langergraber • website: http://www.ecosan.at/ • scope: EcoSan Club was funded as a non profit association in 2002 by a group of people active in research and development as well as planning and consultancy in the field of sanitation. The underlying aim is the realisation of ecological concepts to close material cycles in settlements.

Medieninhaber: EcoSan Club, Schopenhauerstr. 15/8, A-1180 Vienna, Austria • Obmann: Günter Langergraber • Gegenstand des Vereins: Der EcoSan Club wurde 2002 als gemeinnütziger Verein von einer Gruppe von Personen gegründet, die in Forschung, Entwicklung, Planung und Beratung in der Siedlungshygiene - Sammlung, Behandlung oder Beseitigung flüssiger und fester Abfälle aus Siedlungen - tätig waren und sind. Das Ziel des EcoSan Clubs ist die Umsetzung kreislauforientierter Siedlungshygienekonzepte (EcoSan Konzepte) zu fördern, um einen Beitrag zum Schutz der Umwelt zu leisten.

Cover Photo / ***Titelbild***

Editorial

Natural wetlands have been used for wastewater treatment for centuries. In many cases, however, the reasoning behind this use was disposal, rather than treatment and the wetland simply served as a convenient recipient that was closer than the nearest river or other waterway. Constructed treatment wetlands are engineered systems designed and constructed to utilize the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating water. They are designed to take advantage of many of the same processes that occur in natural wetlands, but do so within a more controlled environment.

Constructed treatment wetlands (TWs) are a simple technology in construction as well as in operation and maintenance. They have a high buffer capacity for hydraulic and organic load fluctuations as well as a high robustness and process stability. TWs are therefore a suitable technological solution for small villages and single households and are becoming more and more popular all around the world for treating different types of water. Currently, the estimated number of CW systems in Austria is more than 3000.

Issue 12 of ***Sustainable Sanitation Practice (SSP)*** on **„Treatment wetlands“** includes 6 contributions:

1. the Austrian experience with single-stage sand and gravel based vertical flow systems with intermittent loading (the Austrian type is for treating mechanically pre-treated wastewater),
2. the French experiences with two-stage vertical flow systems treating raw wastewater.
3. EcoSan Club‘s experiences with TWs in Uganda,
4. results from multi-stage TW treating raw wastewater in Morocco.
5. results from horizontal flow experimental systems from Egypt, and
6. experiences from Denmark and UK on reed beds treating excess sludge from activated sludge plants.

The thematic topic of SSP‘s next issue will be „Faecal sludge management“ (issue 13, October 2012). Information on further issues planned is available from the journal homepage (www.ecosan.at/ssp). As always we would like to encourage readers and potential contributors for further issues to suggest possible contributions and topics of high interest to the SSP editorial office (ssp@ecosan.at). Also, we would like to invite you to contact the editorial office if you volunteer to act as a reviewer for the journal.

SSP is available online from the journal homepage at the EcoSan Club website (www.ecosan.at/SSP) for free. We also invite you to visit SSP and EcoSan Club on facebook (www.facebook.com/SustainableSanitationPractice and www.facebook.com/EcoSanClubAustria, respectively).

With best regards,
Günter Langergraber, Markus Lechner, Elke Müllegger
EcoSan Club Austria (www.ecosan.at/ssp)

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Treatment wetlands in Austria: Practical experiences in planning, construction and maintenance

This paper presents information on practical experiences with constructed wetland systems in Austria.

Author: Gabriele Mitterer-Reichmann

Abstract

In this paper we report our experience regarding design, operation and maintenance of constructed wetlands (CWs) for treating domestic wastewater in Austria. About 1600 vertical flow (VF) CWs have been constructed by our company Ökologisches Projekt Ltd (ÖP ltd) during the last 20 years. The company also provides operation and maintenance services for owners of CWs and carries out the yearly monitoring for about 750 systems. Based on these experiences we present our considerations and recommendations concerning the operation of constructed wetlands.

Introduction

2008 in Austria about 93 % of the wastewater is collected in central sewers and biologically treated. For the remaining small rural settlements and single households decentralised small scale biological treatment is more feasible for economic and ecologic reasons. In the beginning of the 1980's the first horizontal flow constructed wetlands went into operation in Styria. Since the 1990's vertical flow constructed wetlands are favoured because also small scale treatment plants have to fulfil nitrification according Austrian effluent standards (1.AEVkA, 1996). The effluent standards for plants <500 PE are:

COD:	90 mg/L
BOD_5:	25 mg/L
NH_4-N:	10 mg/L (T>12° C)

Meanwhile some thousand CWs are in operation (the estimated number is between 3000 and 4000), most of them in the province Styria. The most common application for CW systems is treatment of domestic wastewater. Additionally, reed beds are used to dewater and stabilize excess sludge from technical plants and sludge from primary pre-treatments.

To reach a steady treatment efficiency operators have to observe some operation and maintenance measures. The water authority prescribes a regular monitoring by the operator plus a yearly report of an external professional which has to prove the observance of the effluent standards.

CW System description – *Type Ökologisches Projekt*

Figure 1 shows a sketch of the system components of the CW system *„Type Ökologisches Projekt"*. The system comprises a mechanical pre-treatment, an intermittent tank and the VF filter bed. In the following a description of the technical components is given:

Key factors:

- In Austria constructed wetlands have developed from an alternative solution to a conventional and well accepted technology for wastewater treatment in rural areas.
- The typical Austrian CW system comprises mechanical pre-treatment, an intermittent tank for storing the wastewater for the intermittent loading and a VF filter bed.
- According to the Austrian design standard the VF filter bed is designed with a specific surface area of 4 m² per people equivalent.
- With this design the stringent Austrian effluent requirement regarding nitrification can be met.
- Regular checks by the plant operators plus a yearly external plant inspection within a maintenance contract help to detect or rather prevent malfunctions of the CW system.

1. Mechanical pre-treatment

Usually a 3 chamber septic tank is used which has a minimum volume of 3 m^3 and minimum volume of 0.3 m^3 per person equivalent (PE).

2. Intermittent feeding system

Through intermittent feeding the pre-treated wastewater is loaded to the VF filter area intermittently. The wastewater is distributed on the whole surface through perforated pipes.

Depending on the terrain there are different options for loading the beds: the presence of a difference in height between the pre treated wastewater and the filter bed allows the utilization of mechanical devices without using electric, fossil or solar energy. Usually a quantity related feeding by a float switched pump or by energy free valve is applied.

The valve works according to the principles of buoyancy respectively repression. E.g., Type RV 250 delivers 250 litres per minute; RV 500 delivers 500 litres per minute. 84 % of the ÖP systems are equipped with the valve, 15 % of the intermittent loading systems are using pumps, and 1 % of the plants are equipped with tipping buckets.

3. Vertical flow filter bed

The VF filter bed has an average area of 4-6 m^2/PE, an overall depth of 0.9 to 1.1 m and 1 % slope at the bottom. It is sealed with HDPE foil. The filter media used in a VF bed from bottom to top are:

- 20-40 cm gravel 4-8 mm
- 50-60 mm washed sand 0.06-4 or 1-4 mm (d_{10}>0,17 mm)
- 20-40 mm gravel 4-8 cm

Crosswise pipes with DN 100 and longitudinal with DN 25 or DN 50 are laid on concrete bricks in order to have open space between gravel surface and distribution pipes. An even distribution of the wastewater on the whole surface has to be achieved.

The efficiency of the loading is dependent 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.

A control shaft is situated at the longitudinal end of the filter bed so that the water level can be adjusted by a flexible pipe. The height of the water level in the VF is about 10 cm.

The filter beds are planted mainly with common reed (*Phragmites australis*).

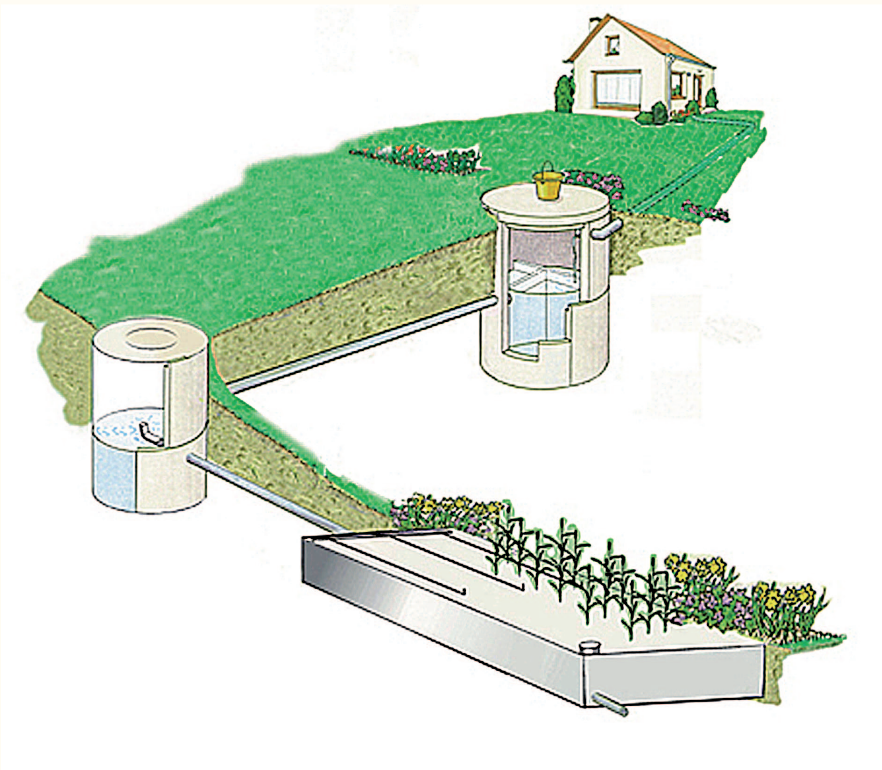

Figure 1. Schematic sketch of the system components of a CW system *„Type Ökologisches Projekt“*

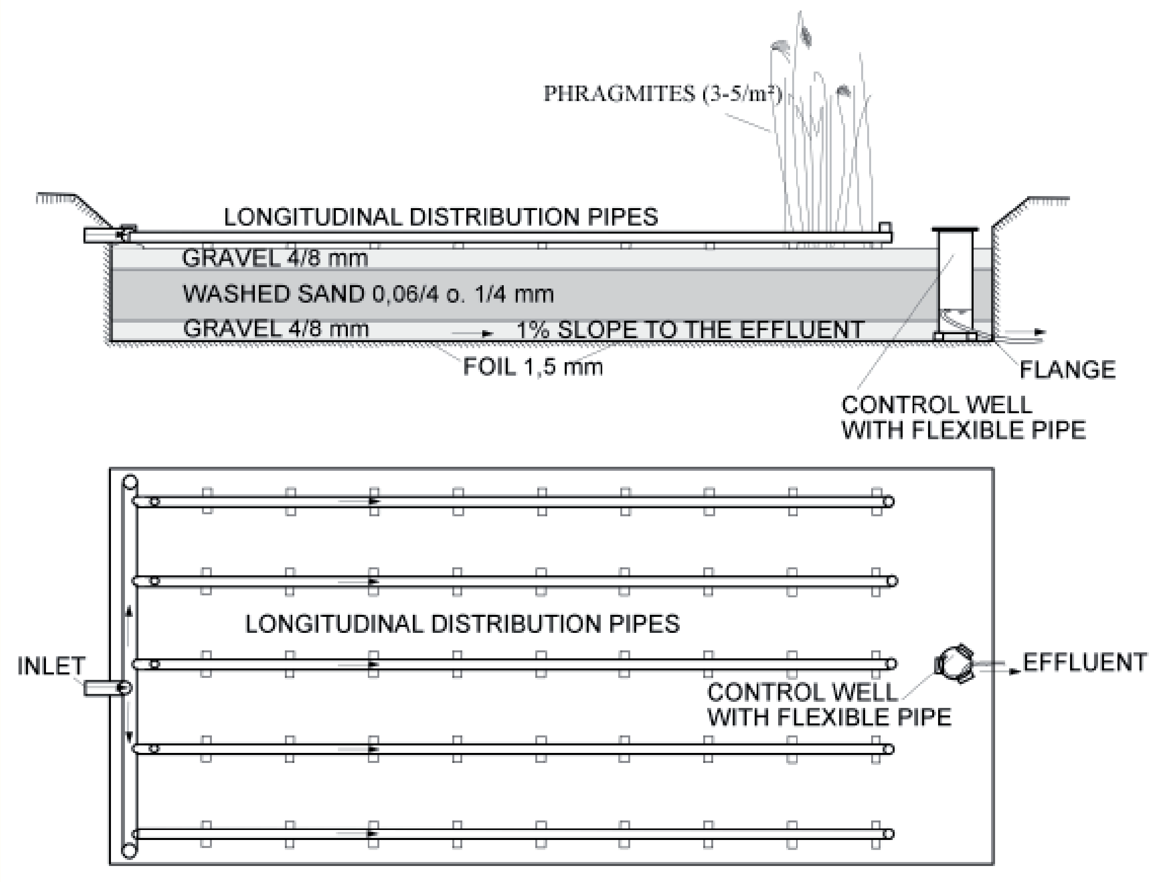

Figure 2. Sketch of the VF filter of the CW system *„Type Ökologisches Projekt“*

Table 1 gives an overview on the number of these systems designed and constructed by the company during the last 20 years. In total about 1600 CW systems have been constructed.

Table 1: Number of CW systems constructed

Person equivalents (PE)		
from	to	number of plants
-	4	2 19
5	10	784
11	12	295
13	20	158
21	40	80
41	50	28
51	100	14
101	800	5*)
Total		**1578**

*) combinations of technical treatment plant and CWs

Treatment effciency

To illustrate the treatment efficiency the effluent analyses made in the year 2011 within maintenance contracts are ranked in categories according to the NH_4-N concentration (Table 2).

Table 2: NH_4-N effluent concentrations in 847 samples of 2011

NH_4-N (mg/L)				
Category	from	to	n	%
1	0	1	596	70
2	1	10	172	20
3	10	20	50	6
4	20	30	14	2
5	30	40	7	1
6	>40		8	1
Total number of samples:			**847**	**100**

The first two categories (90 % in total) are within the limit of the effluent standard of 10 mg NH_4-N/L, 70 % are even below 1 mg NH_4-N/L. 302 samples were taken at wastewater effluent temperatures <12°C showing that nitrification effluent requirement can be fulfilled with VF CWs also at lower temperatures. The figures show that the applied design and construction are appropriate for the treatment of domestic wastewater. The analysed plants are between 1 and 20 years old. At the beginning of this period in 1991 a specific surface area of 6 m² filter area per PE has been used for designing the VF beds, later 4.5 -5 m²/PE. According to the new Austrian design guidelines for CWs (ÖNORM B 2505, 2009) 4 m²/PE is state-of-the-art. Compared to the design guidelines of other countries the sizing of the Austrian type is rather big but requested to guarantee safe operation of the systems during the winter months. This explains why they are robust and show good treatment efficiency also during cold temperatures.

Problems and difficulties in design, planning, construction and maintenance

In the following chapter the most common problems and difficulties in design, planning, construction and maintenance are listed:

Design, Planning

Lack of data for water quantity and load

The dimensioning based only on the number of persons often is not feasible in practice. Some households are not equipped with water meters, especially when they derive the water from their private water well. There is lack of real quantities and loads which leads to over- or under dimensioned treatment plants. This is why a certain effort should be taken over to gain realistic figures. It has shown that there is a broad range in the concentration of domestic wastewater (Table 3).

Construction

Deficient retention of surface water - superficial runoff

Soil substrate from surroundings is washed in the filter and causes clogging of the gravel and sand layers. To prevent this border strips should be established around the filter beds.

Unsuitable filter media

For economical and ecological reasons it will be intended to derive sand and gravel from near as possible to the building object; when new providers are introduced the grain size of the sand should be tested. Until now problems have aroused through the use of too fine sands which led to clogging of the filter.

Uneven building of the slope of the sand layers

Poundage of water in single areas of the filter bed might lead to soil clogging.

Intermittent feeding system not adjusted for filter area

No even distribution above the filter leads to water logging, in succession soil clogging might occur.

Displacement of distribution pipes

See point above

Table 3. Inlet concentrations according Austrian design guidelines and analyses made by ÖP ltd. in 2011 (in mg/L)

Parameter	ÖNORM B 2505 (2009)	Analyses by ÖP ltd., n=71		
		Mean value	Min	Max
CSB	-	663	326	2607
NH_4-N	66	88,9	58,1	339

Different additional treatment requirements in different Austrian federal states

Within the 9 Austrian federal states and even within the districts in a federal state different requirements for the effluent quality can be set by the authorities, e.g. the infiltration of effluent wastewater in the ground or the agricultural utilization of sludge of the pre-treatment is allowed in one and forbidden in another province. Additionally, the elimination of phosphorus can be prescribed in one province and not necessary in the other.

Special applications of CWs

In Austria there is still lack of practical experiences for treatment other types than domestic wastewater like in the treatment of milk chamber wastewater, slaughtering wastewater or seepage sewage from the composting process.

Mechanical pre-treatment using a septic tank

Missing dip tubes cause poor detention storage of solid matter.

Poor quality of concrete parts of septic tank and intermittent feeding well causes corrosion and hence sludge drift from three chamber septic tank.

In some cases efflorescence occurs in the concrete wells. If there is not enough aeration through the house, the covers of the concrete wells should be perforated or ventilation of the gases from the wells should be achieved by other means.

Operation and maintenance requirements

It should be aim of a professional service for CWs to detect problems before they become visible in a reduction of treatment efficiency. It is a characteristic of CWs that mistakes in operation are buffered over a long time. In the case of long term these malfunctions might lead to soil clogging. When it is evident in reduced treatment efficiency it can take a long time until they are completely restored.

The plant owners are instructed about the necessary maintenance works and obliged to keep a "maintenance book" documenting weekly or monthly controls of nitrification with a test kit. They also should check the condition of the three chamber septic tank, the intermittent feeding system and the even distribution through the pipe system in regular intervals.

Pre treatment

The sludge of the pre-treatment has to be emptied in time in order to prevent sludge drift into the reed beds. The emptying intervals depend on the size of the pre-treatment system and vary between one year and several years. The sludge can be stabilized in a separate sludge drying reed bed on the spot. Alternatively it can be transported to a central sewer plant for further treatment.

Intermittent feeding system

The functioning of the intermittent feeding by the valve can be checked by measuring the difference in height in the well before and after the feeding process. After some years the rubber part of the flexible pipe can be porous which is why the wastewater seeps continuously only into the front part of the filter bed. If this is not detected the filter will be clogged after some time. This is why the device should be controlled once a month.

Filter bed

During the first year attention should be paid to the growing of the plants. Weeds should be removed until the reed is established.

An uneven distribution of wastewater above the filter is the most common problem of malfunctioning of constructed wetlands. It can be measured by collecting the water flowing out the pipes at the 4 corner points of the filter bed. The distribution system can be best adjusted and cleaned after the cutting of the plants.

The cutting of the plants can be made in spring. Some operators prefer to cut the reed in autumn, lay the dry straw on the filter surface and remove it in spring because then there are less small leave parts on the filter surface. The water level in the filter bed should be as low as possible.

Conclusion

Constructed wetlands have developed from an "alternative green idea" to a conventional and well accepted technology for wastewater treatment in rural areas of Austria.

To keep a high treatment efficiency and steady operation the operators have to observe some maintenance works and regular controls of the system components.

A regular external examination by a professional helps to detect problems and recommendations can be given to the operators. Finally the long term operation is also documented in a "plant history" by the company.

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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.

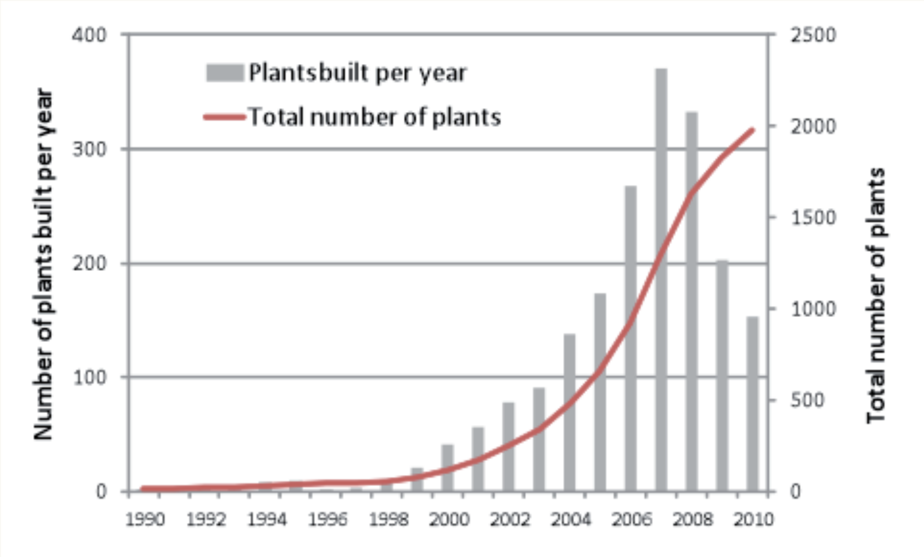

Figure 1: Development of vertical flow CW over time in France (French Ministry data base)

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

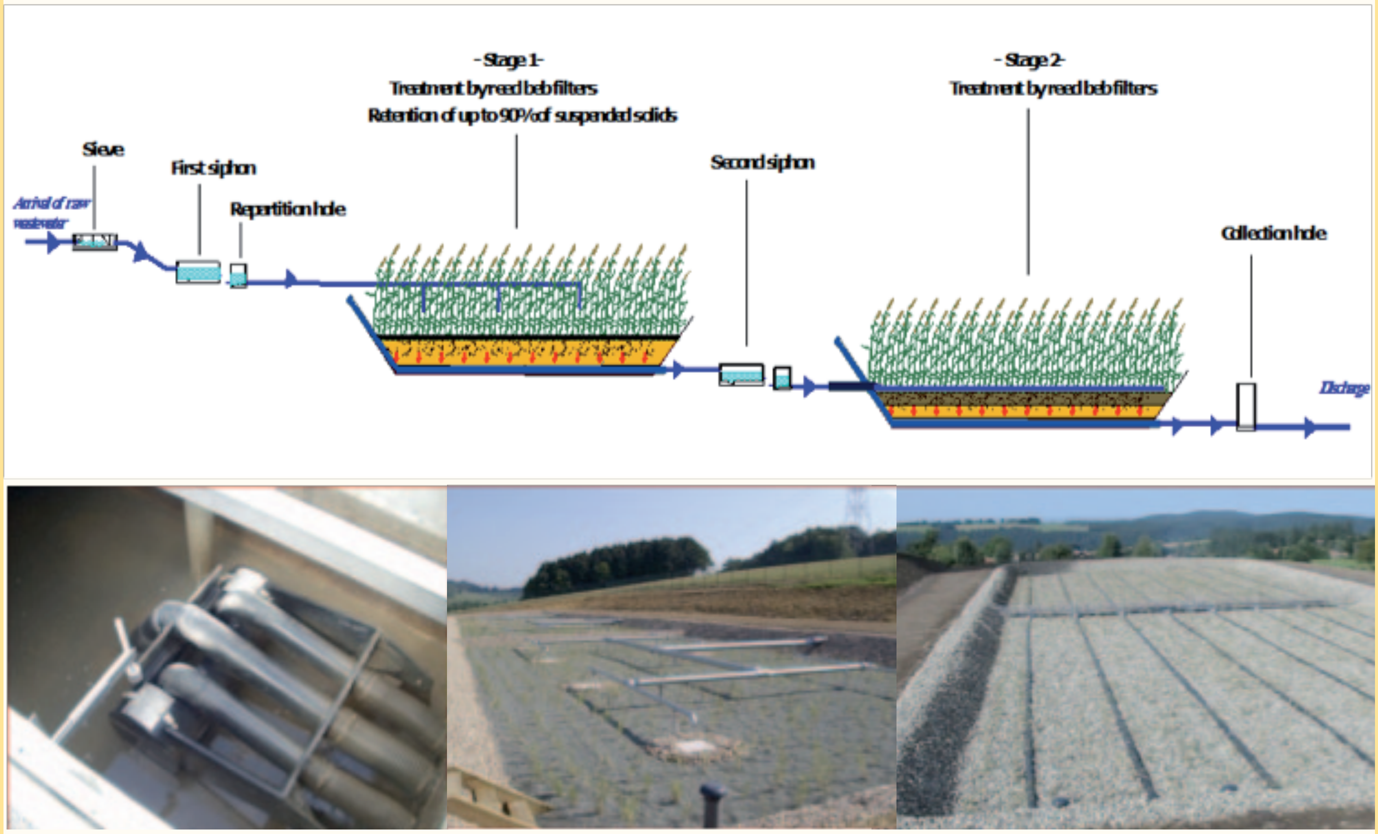

Figure 3: VF CW configuration with siphon

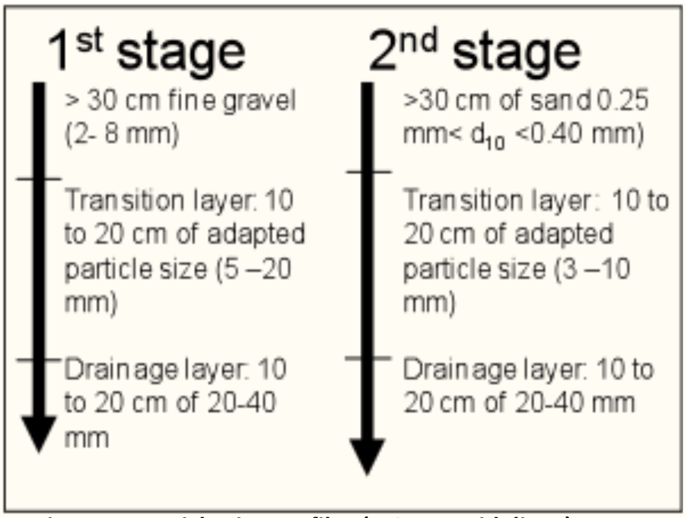

Figure 4: Particle size profiles (IRSTEA guidelines)

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/m^2/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

Pollutant Removal efficiencies

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.

First stage of treatment

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

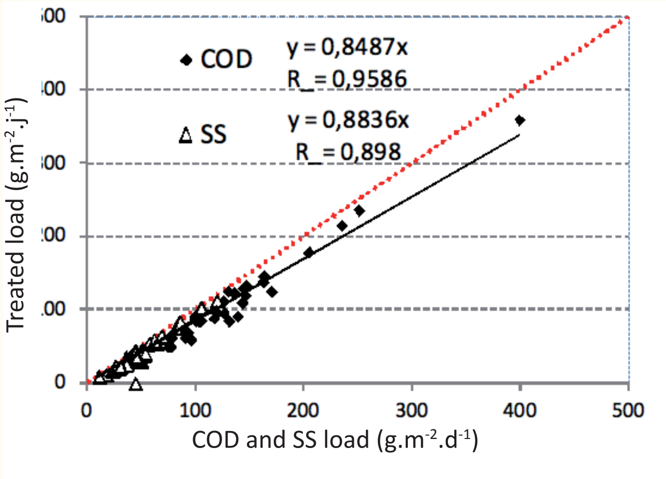

Figure 8: Treated COD and SS on the first stage for 0.1 < HL <1.57 m/d.

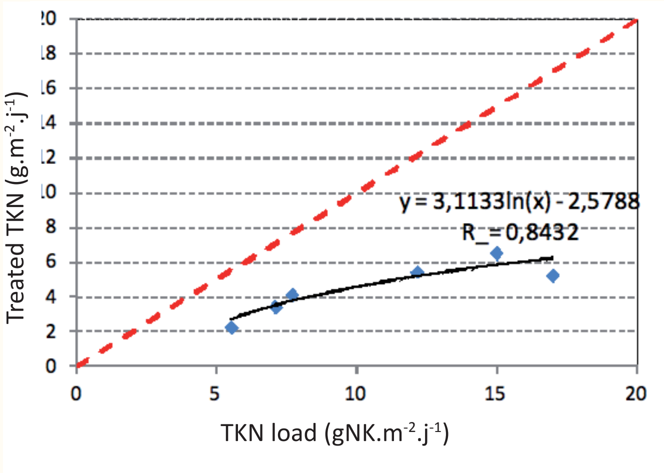

Figure 9: Treated TKN on the first stage for 0.1 < HL <1.57 m/d.

<u>Second stage of treatment</u>

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.

<u>Sludge accumulation and handling</u>

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

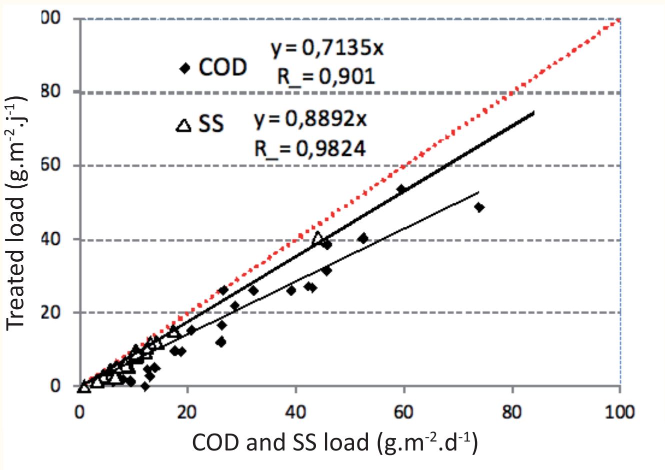

Figure 10: Treated COD and SS on the second stage 0.1 < HL <1.57 m/d.

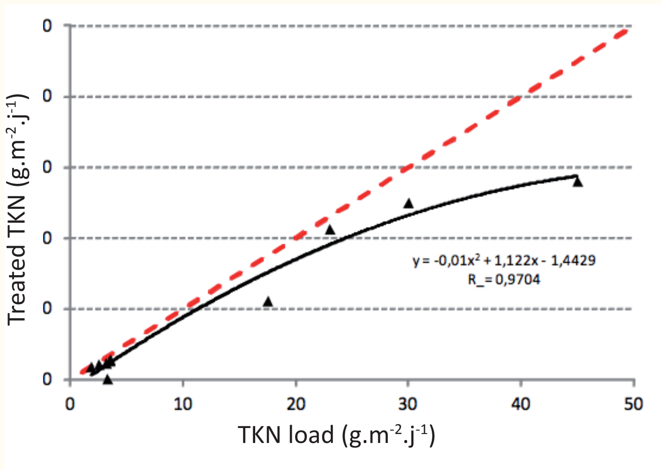

Figure 11: Treated TKN on the second stage 0.1 < HL <1.57 m/d.

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.

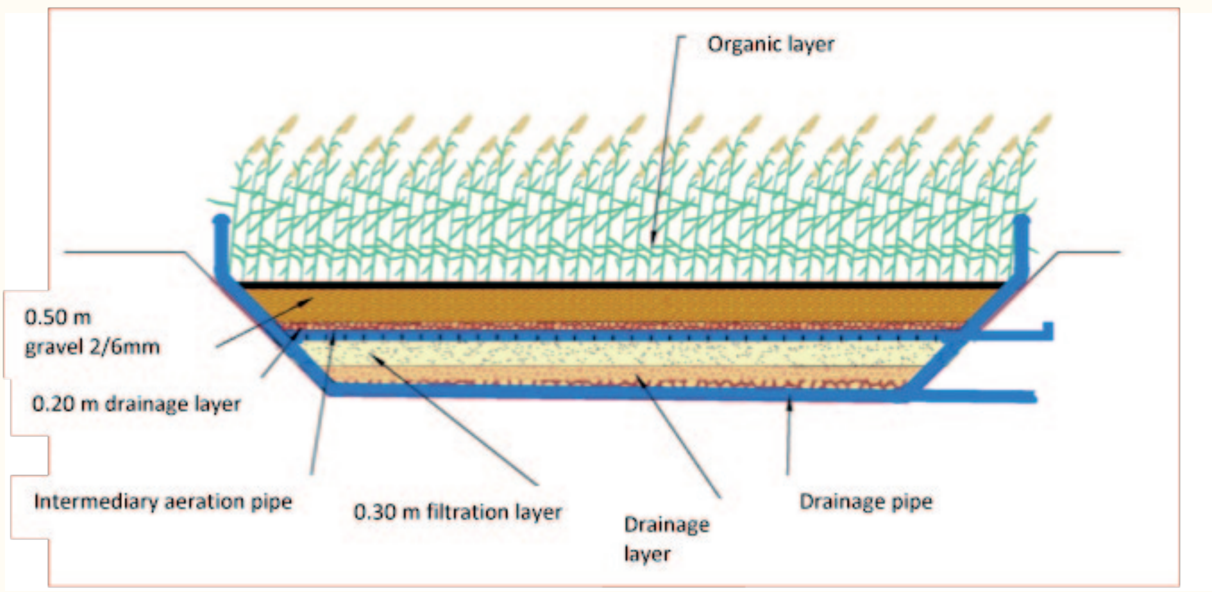

Figure 13: Cross section of a Bi-filtre®

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

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Comparing the treatment efficiency of different wastewater treatment technologies in Uganda

If operated and maintained properly vertical flow constructed wetland systems can fulfil the stringent Ugandan effluent requirements regarding ammonia nitrogen effluent concentrations.

Authors: Muellegger Elke, Markus Lechner

Abstract

The data presented in this paper are focusing on the performance of 5 wastewater treatment systems (2 vertical and 2 horizontal flow constructed wetland (CW) systems and 1 waste stabilization pond) in Uganda. The four CW systems, sizes ranging from 200 to 1000 person equivalents, are all a component of sustainable / ecological sanitation systems.

This study demonstrates that vertical flow CWs show a significantly better performance than the commonly constructed stabilisation ponds. They can be a suitable alternative for wastewater treatment particular for rural areas in Uganda. However, still even minimal maintenance requirements of a vertical flow constructed wetland can pose a problem.

Introduction

In 1998-99 the first vertical flow constructed wetland (CW) system was implemented in Uganda. It was constructed for St. Kizito Hospital Matany, a rural hospital in Western Uganda. Since then, six more CWs (2 horizontal and 4 vertical flow CWs, respectively) have been constructed for different institutions scattered all over the country. These seven CW systems, sizes ranging from 200 to 1000 person equivalents, are all a component of sustainable / ecological sanitation systems. These systems focus on water resources protection, in areas where water is very scarce, and reuse of sanitized human excreta and treated wastewater.

The practise of reuse also bears risks to human beings, animals and the environment. To evaluate the actual health risk related to handling and use of treated wastewater and human excreta the study „Risk of Reuse - Study on the reuse of treated wastewater and sanitised human excreta in Uganda“ (Muellegger, 2010) was conducted. Five Ugandan institutions - three hospitals, one health centre and one school - were part of this study. These institutions are using wastewater and products from human excreta in agriculture.

The data presented in this paper are focusing on the performance of the 5 wastewater treatment systems (2 vertical and 2 horizontal flow CWs and 1 waste stabilization pond). The risk assessment which is based on the methodology adopted by the “WHO Guidelines for the safe use of wastewater, excreta and greywater” (WHO, 2006) is not described here. The data of this study have been already presented by Muellegger and Lechner (2011).

Key messages:

- Only vertical flow constructed wetland (CW) systems can fulfil the requirements regarding ammonia effluent concentrations of the Ugandan regulations.
- Vertical flow CW systems show a good performance as long as maintained regularly.
- Even simple operation and maintenance tasks as required for CW systems can be a problem in rural areas of Uganda.
- Design of CW systems in Uganda needs to take into consideration that usually specific grain size distributions for sand are not available locally; the main layer of CW systems has to be constructed with the sand that is available.
- Design organic loads of more than 50 g COD/m²/d are not recommendable as they may lead to clogging.

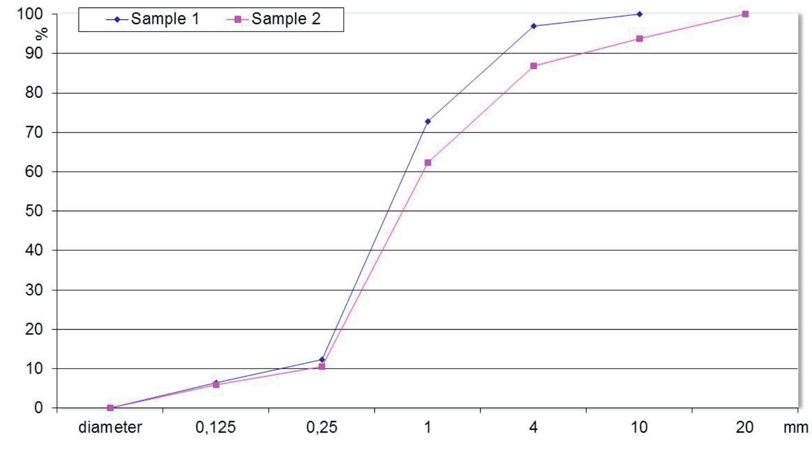

Figure 1: Sieve Analyses Filter Sand at Matany Hospital

Picture 1: Vertical flow CW system in Matany Hospital.

Materials and methods

Site descriptions

Five Ugandan institutions were part of this study: St. Kizito Hospital Matany and Kanawat Health Centre, St. Mary´s Hospital Lacor and Maracha Hospital and Kalungu Girls Secondary School.

St. Kizito Hospital Matany is a rural hospital in the semiarid region of Karamoja, in eastern Uganda. The sanitation system is in operation since 1999. Wastewater from flush toilets and showers is treated in a vertical flow constructed wetland system (Picture 1), with a capacity of 625 PE. The wetland is separated in three individual beds and planted with elephant grass (Pennistum purpureum). A three-chamber settling tank serves as wastewater pre-treatment and a mechanical distribution unit enables an intermittent distribution to the three beds. The treated wastewater is collected in a storage tank for irrigation. Furthermore dried sludge from septic tanks and pit latrines is used as soil conditioner. Both fractions are only used to fertilise trees. The plant was designed for an organic load of 47 g COD/m²/d. For this and all other treatment plants described below locally available sand was used for the construction of the filter. The quality of the sand varies; in the case of Matany Hospital's treatment plant the grading curve is shown in Figure 1.

Kanawat Health Centre is located in the north-east of Karamoja. The sanitation system was completely replaced in 2003 and 2004. Wastewater from flush toilets is treated in a horizontal flow constructed wetland system (Picture 2), with a capacity of 30 PE. The filter bed is planted with elephant grass. A three-chamber settling tank is pre-treating the wastewater and a sludge drying bed was constructed for stabilised sludge from the settling tank. An underground collection tank is storing the treated wastewater for irrigation of trees. Staff of the health centre is using urine diverting dry toilets, one block with four units. The treatment plant was designed for an organic load of 53 g COD/m²/d.

Maracha Hospital is a rural hospital in north-western Uganda. The sanitation infrastructure was rehabilitated in 2001 and 2002. Wastewater is treated in a vertical flow

Picture 2: Horizontal flow CW system in Kanawat Health Centre.

Picture 3: Filter baskets as wastewater pre-treatment in Maracha Hospital.

Picture 4: Horizontal flow CW system in Kalungu.

Picture 5: Inlet into the first pond in Lacor Hospital.

constructed wetland, which has a capacity of 250 PE. The bed is planted with elephant grass. Two intermittently fed filter baskets are serving as pre-treatment (Picture 3) and a distribution chamber enables an even distribution to the filter beds. Treated wastewater is discharged to the environment. Additionally two blocks of urine diverting dry toilets, each with eight toilets, are in use. Sludge from the filter baskets and dried faeces from the urine diverting dry toilets are composted and used in the hospitals own vegetable garden and sold respectively. The treatment plant was designed for an organic load of 65 g COD/m²/d.

Kalungu Girls Secondary School is a rural boarding school in the tropical South of Uganda. The sanitation system is in operation since 2003. Wastewater is treated in a horizontal flow constructed wetland (for 165 PE), planted with elephant grass (Picture 4). The system is treating mainly greywater and a small share of blackwater from three flush toilets. The collected wastewater is pre-treated in a three-chamber settling tank. After treatment it is infiltrated into the ground and not reused as the amount of water is very little. For excreta management 45 single vault urine diverting dry toilets for pupils and one for teachers are in use. The collected faecal material is further treated in a composting area. Dried faeces and urine are used as fertiliser in the school garden. The treatment plant was designed for an organic load of 160 g COD/m²/d.

Lacor Hospital is a rural hospital in Northern Uganda. A conventional pond system (Picture 5) for treatment of mixed wastewater is in operation since the 1990s. In 2005 a "natural filter" has been constructed, because of insufficient treatment of wastewater. The "natural filter" is a fenced area planted with elephant grass, aiming to increase the treatment efficiency of the system. Treated wastewater is not used.

Determination of quality parameters

Sampling and analysis

Grab samples have been taken 6 times between June 2004 and March 2006 from the effluents of the CWs. During the first three sampling rounds most of the wastewater parameters were analysed directly on spot with field testing equipment. Due to problems of transporting the testing equipment by bus, for the last three rounds the majority of parameters were analysed in the laboratory of the National Water and Sewage Corporation (Quality Control Department; Central Public Laboratories) in Kampala.

The following physical and chemical parameters have been analysed: COD, BOD_5, NH_4-N, PO_4-P, SO_4-S, turbidity, pH-value, electrical conductivity (EC) and temperature. Additionally the samples have been analysed for the following heavy metals: cadmium, chromium, copper, lead, nickel, zinc.

Ugandan Discharge Regulation

For the results of the data collection the Standards for discharge of effluent and wastewater in Uganda (Uganda Discharge Regulation, 1999; Table 1) were used as reference.

Results and discussion

Physico-chemical parameters

<u>Vertical flow constructed wetlands</u>

Table 2 compares the results of the two vertical flow CWs which are both located in the semiarid part of Uganda. The CW in Matany is working since 12 years without problem which was confirmed by the low outflow concentrations. The CW in Matany is using a septic tank as pre-treatment unit, which is emptied once a year. The Maracha CW, on contrary, had continuous problems with the pipe valves of the

Table 1: The standards for discharge of effluent and wastewater in Uganda (The Water (Waste) Discharge Regulations, 1998).

Uganda Discharge Regulation (1999)					
Physico-chemical parameters			**Heavy metals**		
COD	mg/L	100	Cd	mg/L	0,1
BOD5	mg/L	50	Cr	mg/L	1
NH4-N	mg/L	10	Cu	mg/L	1
PO4-P	mg/L	10	Pb	mg/L	5
SO4-S	mg/L	500	Ni	mg/L	1
Turbidity	NTU	300	Zn	mg/L	0,1
Ph value	-	6-8			
El. conductivity	µS/cm	--			
Temperature	°C	--			

distribution chamber. This was mainly due to the fact that maintenance of the system was neglected. The non-functional pipe valves are mainly responsible for a lack of oxygen thus resulting in a higher NH_4-N effluent concentration.

Horizontal flow constructed wetlands

Table 3 compares the results of the two horizontal flow CWs. Both are in operation since nearly eight years and are used mainly to treat greywater. The treatment system in Kanawat had only problems with too high NH_4-N concentrations which could be attributed to unplanned urine discharge into the sewer system. The analysis in Kalungu showed very unsatisfactory results. The main reasons are the instability of the hydraulic load, which fluctuates strongly over the year and the comparatively high design load. Especially during holidays, the hydraulic load is reduced to a minimum and the wetland oversized while during school the system is overloaded.

Vertical flow vs. horizontal flow CW

The results presented in Table 2 and Table 3 demonstrate the expected improved nitrification efficiency of vertical flow constructed wetlands. The untypically high NH_4-N effluent concentration of the

Table 2: Characteristics of the vertical flow CW effluents.

VERTICAL FLOW CW		MATANY			MARACHA		
Parameter		#	Average	Stdev	#	Average	Stdev
Physico-chemical paramters							
COD	mg/L	6	86	48	5	130	70
BOD5	mg/L	4	20	14	2	14	2
NH4-N	mg/L	3	1,4	0,5	5	43,4	28,2
PO4-P	mg/L	5	7,8	1,9	6	10,0	14,7
SO4-S	mg/L	3	34,7	6,1	3	26,7	6,0
Turbidity	NTU	4	7,1	9,1	4	17,0	15,6
Ph value	-	5	7,1	0,7	5	6,8	1,2
El. conductivity	µS/cm	5	1550	147	5	1841	360
Temperature	°C	4	25,8	2,1	4	26,2	1,8

Table 3: Characteristics of the horizontal flow CW effluents.

HORIZONTAL FLOW CW		KANAWAT			KALUNGU		
Parameter		#	Average	Stdev	#	Average	Stdev
Physico-chemical paramters							
COD	mg/L	6	87	31	5	121	31
BOD5	mg/L	3	22	4	3	65	7
NH4-N	mg/L	6	46,6	27,3	5	29,2	15,1
PO4-P	mg/L	5	5,8	2,4	4	7,5	5,5
SO4-S	mg/L	3	43,3	9,0	2	34,5	6,4
Turbidity	NTU	4	18,8	22,1	3	34,0	27,6
Ph value	-	5	7,7	0,2	4	7,4	0,6
El. conductivity	µS/cm	5	2046	375	4	1145	332
Temperature	°C	4	24,4	2,6	5	23,9	2,5

Maracha treatment plant is due to maintenance issues. Frequent problems with keeping the pipe valve, which controls the intermittent discharge to the filter beds, operational result in insufficiently equal distribution of the wastewater and lack of oxygen supply into the soil matrix.

Pond system

Table 4 shows the results of the pond system in Lacor. The results show significantly higher effluent concentrations for COD, BOD_5 and NH_4-N in comparison to constructed wetlands. Higher COD and BOD concentrations are probably at least partly due to algae which can not be retained in the system (compare the lower COD/BOD ratio compared to constructed wetlands as well as higher turbidity) while the higher NH_4-N concentration shows insufficient supply of oxygen for nitrification.

Table 4: Characteristics of the pond system effluent.

PONDS			LACOR	
Parameter		#	Average	Stdev
Physico-chemical paramters				
COD	mg/L	6	176	78
BOD5	mg/L	3	65	23
NH4-N	mg/L	6	59,9	15,8
PO4-P	mg/L	6	6,3	3,5
SO4-S	mg/L	3	5,0	2,6
Turbidity	NTU	4	68,3	37,0
Ph value	-	5	6,7	1,2
El. conductivity	µS/cm	6	918	278
Temperature	°C	5	23,7	2,7

Heavy metals

The analysis for heavy metals showed that in most samples the concentration was below the Ugandan standards, only few samples exceeded the limits. Scattered higher levels of copper, nickel, cadmium and lead have been measured. The main sources of high lead, cadmium and nickel concentrations in wastewater are discarded nickel-cadmium (WHO, 2003) and lead-acid (WHO, 2008) batteries thrown into the toilets. High copper concentrations may result from corrosion of interior copper plumbing, which may occur in standing water in copper pipes (WHO, 2008).

Operation and maintenance (O&M) as key factor for sustainability

Maximum benefit of an improved sanitation infrastructure can only be achieved when the facilities operate continuously and at full capacity in conformity with national standards of quantity and quality. In practice, O&M of sanitation systems, especially in developing countries, receives less attention compared to the design and construction phases, or it is even completely neglected (Muellegger et al. 2010; Hierzegger et al., 2012). The CWs in Uganda proof these statements:

- Matany Hospital and Kanawat Health Centre have employees who are responsible for the CW systems. Besides the regular maintenance works they are also emptying the septic tank once a year, resulting in well performing CW systems.

- In Maracha Hospital also operators for the sanitation system are employed. However, the distribution chambers are not cleaned regularly thus the pipe valves are not working, resulting in poor performance. A similar problem exists in Kalungu, where the septic tank is not cleaned regularly.

Recommendations for implementation of CWs in Uganda

Commonly it is assumed that technical wastewater treatment plants are not applicable for (rural areas in) Uganda. The main reasons are unreliable power supply and lack of technical capacities for operation and maintenance. Therefore commonly stabilisation ponds are designed as a standard solution. However looking at National Standards (The National Environment Regulations, 1999) and expected and measured performance of stabilisation ponds it is clear that as far as nitrification is concerned these standards cannot be reached. This study demonstrates that vertical flow constructed wetlands show a significantly better performance and can be a suitable alternative for wastewater treatment in particular for rural areas in Uganda. Still even minimal maintenance requirements of a vertical flow constructed wetland - in the case of the treatment plant in Maracha the pipe valve for intermittent discharge - can pose a problem.

Nevertheless further research is required when it comes to nitrogen elimination as required according to Ugandan National Standards (Total N <10mg/L; The National Environment Regulations, 1999). Furthermore one major issue related to technical design is the quality of filter media available locally. While European design guidelines generally assume the availability of uniform filter media this is not the case in Uganda. Material which is available locally or at least within close vicinity has to be used for cost and logistical reasons. A design methodology therefore by necessity should take the characteristics of the material into consideration rather than assuming a certain quality.

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A Hybrid Wetland for Small Community Wastewater Treatment in Morocco

This paper presents design parameters for a hybrid constructed wetland and tentative strategies for optimizing treated effluent reuse for irrigation.

Authors: Bouchaib El Hamouri, Christopher Kinsley, Anna Crolla

Abstract

A pilot hybrid constructed wetland system was established in 2007 at the Institut Agronomique et Véterinaire Hassan II (IAV) in Rabat, Morocco aiming at: i) adapting constructed wetland technology to small communities in Morocco ii) defining tentative nitrogen management strategies for durable effluent reuse applications. The three stage system includes a primary vertical flow wetland, a secondary horizontal flow wetland and a tertiary vertical flow sand filter. Recirculation from stage three to stage two was used to prompte denitrification. The system reduces COD by 95%, TSS by 94% and E.coli by 2.6 logs. Total nitrogen is reduced by 65% with a recycle rate of 100% which balances nitrogen demand for irrigated crops in arid regions. This passive wetland technology has been shown to function well under Moroccan climatic conditions and provides a low cost wastewater treatment system for small communities.

Introduction

Morocco, as with other countries in North African and the Middle East, is situated predominantly in arid and semi-arid climatic zones and is confronted with a growing water crisis. Agriculture remains the primary consumer of water at 88 percent of mobilised water resources and it is projected that available water resources will decline from 1000 m^3/cap/yr in 2000 to 570 m^3/cap/yr in 2025 (Government of Morocco, 2001). As well, wastewater treatment in rural areas of Morocco is significantly lacking, with uncontrolled discharge. Due to a lack of irrigation options, farmers often use untreated wastewater and subject themselves and consumers to significant health risks. In the case of Morocco, approximately 70 million m^3 of untreated wastewater are used each year without any sanitary precautions to irrigate an area of more than 7000 hectares (El Kettani et al., 2008).

A pilot hybrid constructed wetland system was established in 2007 at the Institut Agronomique et Vétérinaire Hassan II in Rabat, Morocco in order to adapt constructed wetland technology for small community wastewater treatment and agricultural reuse under Moroccan climatic conditions.

Technical Data:

The pilot wetland system consists of three stages: a primary vertical flow wetland, a secondary horizontal flow wetland and a tertiary vertical flow sand filter. Design details include:

- Design flow = 12 m^3/d
- Total system occupies 4.5 m^2 per person equivalent (PE)
- Three primary vertical flow wetlands operated in sequence with 4 d operation and 8 d rest period. Hydraulic loading rate = 0.5 m/d
- Horizontal flow wetland residence time = 3.1 d
- Vertical flow sand filter hydraulic loading rate = 0.25 m/d
- Optimum recycle rate for denitrification = 100%

Overview of the Wastewater Technology

Hybrid Constructed Wetland Technology

The hybrid wetland technology is depicted in Figure 1 and consists of three stages: a primary vertical flow (VF) wetland to remove solids, a secondary horizontal flow (HF) wetland to remove organic matter and nitrogen and a tertiary VF sand filter to remove pathogens and to nitrify effluent. Wastewater is recycled from Stage 3 to Stage 2 to promote denitrification.

The first stage is a primary VF wetland following the CEMAGREF design (Molle et al., 2005). The filter consists of: a 15 cm drainage layer of 20-40 mm gravel, a 10 cm intermediate layer of 10-20 mm gravel and a 30 cm layer of 8-10 mm gravel (Figure 2 and Figure 3). Three filters (5 x 5 m) are planted in native *Phragmites australis*. Each filter is dosed for 4 days at 12 m^3/day followed by an 8 day rest period. The primary filter receives raw wastewater and removes solids and organic matter through filtration and biological treatment. Organic matter accumulates in the filter and mineralizes over time. Root penetration and wind induced swaying of the Phragmite stems act to maintain drainage pathways and alleviate clogging of the filter surface.

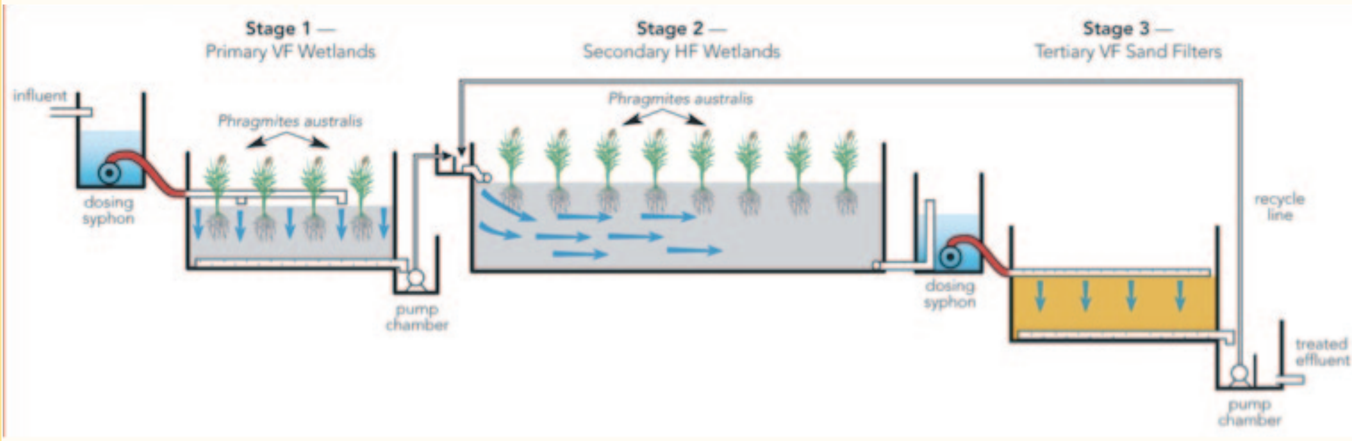

Figure 1: Hybrid Pilot Wetland Cross-Sectional View

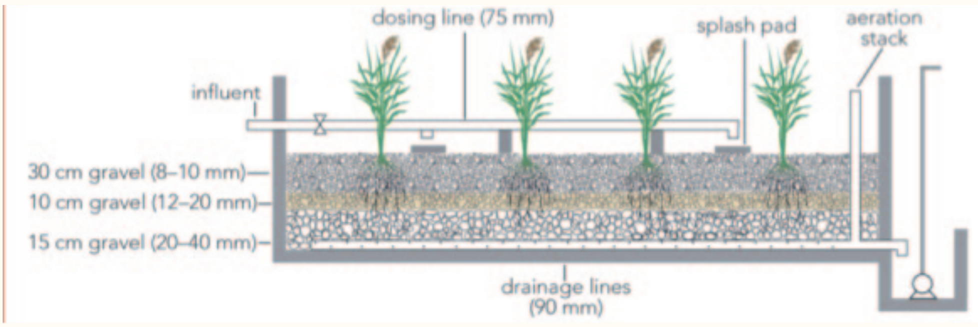

Figure 2: Primary VF Wetland Cross-Sectional View

Figure 3: Primary VF Wetland - Photos (2007, left, and 2011, right)

The second stage is a HF wetland planted in native *Phragmites australis* (Figure 4 and Figure 5). The wetland sizing is based on first order kinetics for removal of organic matter (Young et al., 1998; El Hamouri, 2007). The HF wetland consists of three parallel cells of 20 m × 2.45 m each with a depth of 0.65 m of 12-20 mm gravel (middle cell unplanted). The HF wetland has a hydraulic retention time of 3.1 days.

The third stage is comprised of a series of three VF sand filters in parallel for nitrification and pathogen attenuation (Figure 6 and Figure 7). The design is based on a single pass sand filter designed for nitrification (Crites and Tchobanoglous, 1998; Cooper, 2005). Each filter (4 x 4 m) consists of: a 20 cm drainage layer of 12-20 mm gravel, a 40 cm layer of 1-5 mm washed sand and a 20 cm layer of 12-20 mm gravel.

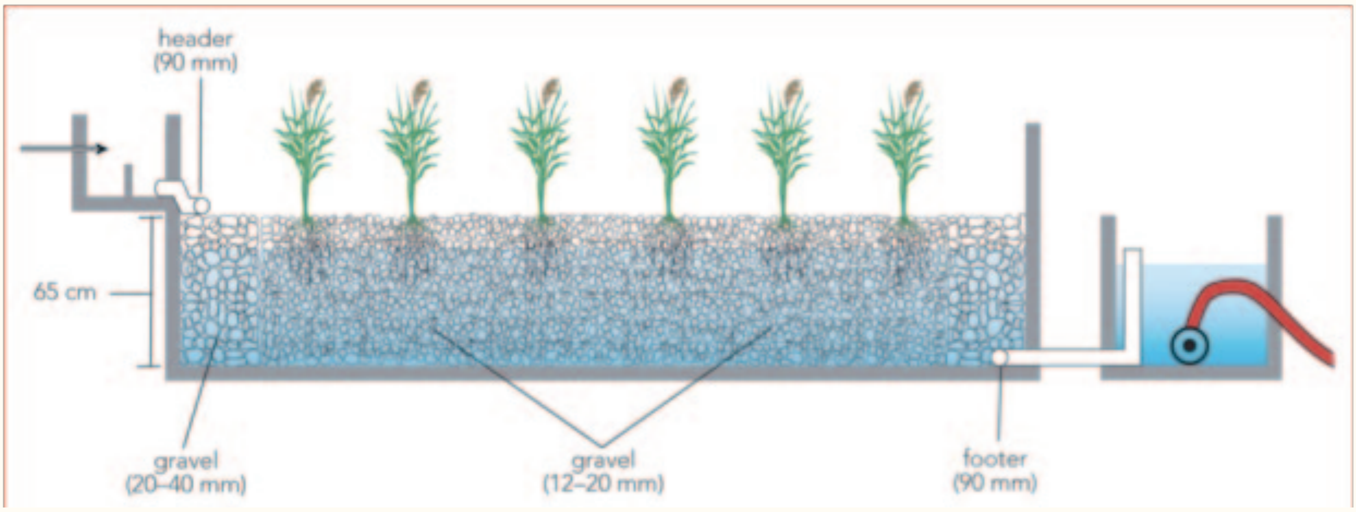

Figure 4: Secondary HF Wetland Cross Sectional View

Figure 5: Secondary HF Wetland Photos (2007 & 2008)

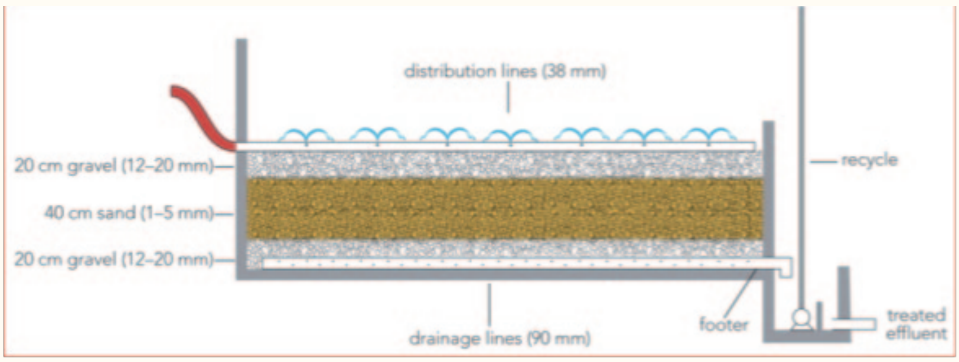

Figure 6: Tertiary VF Sand Filter Cross Sectional View

Figure 7. Tertiary VF Sand Filter Cross Photo (2011)

System Performance

Performance of the hybrid wetland technology is presented in Table 1.

Organic Matter and Solids

The CW system is very effective at removing organic matter and solids with most of the organic matter and solids removed after the HF wetland. For restricted wastewater reuse (i.e. irrigation of forage crops or cereals), TSS must be below 100 mg/L (Government of Morocco, 2002). This level of treatment is achieved by the HF wetland stage. Therefore, if a secondary quality effluent is required, it is not necessary to include a tertiary VF sand filter in the design.

Nitrogen

A total nitrogen reduction of 65% was achieved with a recycle ratio of 100%. The VF sand filter was effective at nitrifying the ammonia from the HF wetland and the anoxic conditions in the HF wetland were conducive for denitrification. It is important to reduce total nitrogen levels prior to irrigation as nitrogen is often in excess of crop requirements and could contaminate groundwater resources.

Irrigation and nitrogen requirements are given for several crops for the irrigated region of Tadla, Morocco which receives annual average precipitation of 268 mm/yr (Berrada, 2009) (see Table 2). Calculations were based on total nitrogen concentrations ranging from a typical value of 70 mg/L (Crites and Tchobanoglous, 1998) to the 115 mg/L reported in this study (see Table 1). Nitrogen from treated wastewater meets crop N requirements in most cases when 65 % is removed through recirculation. Therefore, recirculation to

Table 1: Hybrid Wetland Performance (Avg. ± Std. Dev.)

	COD (mg/L)	TSS (mg/L)	TN (mg/L)	E.coli (CFU/100mL)
Raw Wastewater	746 ± 137	328 ± 94	115 ± 11	5.6×10^{6}
Primary VF Wetland	199 ± 38	62 ± 32	68 ± 27	3.0×10^{6}
Secondary HF Wetland	56 ± 13	25 ± 21	40 ± 14	2.1×10^{5}
Tertiary VF Sand Filter	35 ± 15	20 ± 26	40 ± 14	1.5×10^{4}
Removal Rate	95%	94%	65%	2.6 log

Table 2: Example of Crop Nitrogen Demand met by Wastewater Reuse (Tadla, Morocco)

Crop	Irrigation Water Requirement 1 (m^3/ha/year)	Plant N Requirement (kg/ha/year)	Wastewater N Supplied	
			With No Recirculation (40% removed) (kg/ha/year)	With Recirculation (65% removed) (kg/ha/year)
High N Required e.g. alfalfa, grain corn, citrus and olive plantations [2]	>8000	200-300	336-550	200-320
Medium N Required e.g. wheat [3]	4000	100-150	168-280	100-160
Low N Required e.g. barley	2500	80-120	105-170	63-100

[1] Belabbes, 2004; [2] Walali et al., 2003; [3] Moughli and Cherkaoui, 2002

promote denitrification will often be necessary to avoid nitrate contamination of the groundwater in arid regions with significant water demand.

Pathogens

The two pathogen indicators governing wastewater reuse are E.coli bacteria and helminth eggs. E.coli numbers are reduced by 2.6 logs throughout the system from 5.6 x 10^6 in the raw wastewater to 1.5 x 10^4 CFU/100mL at the outlet of the VF sand filter. Although not enumerated in this study, helminth eggs are effectively removed through filtration and will likely be removed in the first filter, as they are closely associated with wastewater sludge (Kengne et al., 2009).

For unrestricted reuse (i.e. irrigation of produce eaten raw) pathogen standards are typically 10^3 CFU/100mL E.coli and <1 helminth egg/litre (WHO, 2006). A further disinfection step would therefore be required as the VF Sand Filter reduces E.coli to only 1.5 x 104 CFU/100mL.

Conclusions

The hybrid constructed wetland technology is a promising wastewater treatment alternative for small communities in Morocco and for communities with comparable socio-economic and climatic conditions. The system has been shown to function well over four years of continuous operation. The passive wetland technology provides several advantages including: low capital and operating costs, low energy requirements and high levels of treatment. The system produces tertiary quality effluent suitable for direct discharge or for irrigation of forage crops, cereals and fruit trees while reducing pathogen risk and protecting groundwater from excess nitrogen leaching.

Acknowledgements

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Constructed Wetlands for Urban Wastewater Treatment in Egypt

Results shown in this paper reveal that the investigated CW is capable of treating domestic wastewater in Egypt up to an acceptable environmental level suitable for agricultural reuse.

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Abstract

Constructed-Wetlands (CWs) with horizontal subsurface flow (HSSF) have been implemented as secondary treatment of urban wastewater at Ismailia. The system consists of two treatment stages in sequences. Each stage consists of 6 channels. Raw wastewater was subjected to sedimentation followed by a trickling filter and then to the CW system with a flow rate of 20 L/min to each CW bed. The total treated volume was 100 m^3/d. The CWs have been operated intermittently; the flow of wastewater was 18 hours. The daily cycle provides sufficient time for the channels to dry and allow atmospheric oxygen to diffuse into the root zone. Physical, chemical and biological characteristics of the wastewater influent and effluent were studied for a period of eight months. Removal of BOD_5, Suspended Solids and Ammoniacal-N ranged from 70 % to 93 %. Effective elimination of the pathogenic bacteria was achieved. Overall results reveal that the CW is capable of treating domestic wastewater in Egypt up to acceptable environmental level suitable for reuse in agriculture purposes.

Introduction

Within the last 30-35 years various types of constructed wetlands (CWs) have been developed in different countries. There is a wide international acceptance and interest because of many advantages of this system including low cost to build compared to other treatment options, simple construction, operation, maintenance, and very low energy consumption (Hammer, 1989; Cooper et al., 1996). CWs have other advantages including high ability to tolerate fluctuations in flow and inlet quality, high process stability due to a high buffer capacity (Crites and Tchobanoglous, 1998; Abdel-Shafy et al., 2008). Sludge is produced only in the primary treatment stage (Masi et al. 2010). CW systems proved to be an efficient technology for physical, chemical and biological treatment of wastewater (Kadlec and Knight, 1996, Masi et al., 2008).

Treatment of domestic or municipal wastewater and ecological sanitation is currently a conventional application (Crites and Tchobanoglous, 1998, Kadlec and Knight, 1996, Otterpohl, 2004). There are several thousands of operating wetlands worldwide, the most used are the subsurface flow systems (Masi et al. 2010, Bulc et al., 2003). The most available monitoring data are related to this kind of application. Meanwhile, there are numerous possibilities also for industrial wastewater like heavy metals, chemical industry, laboratory effluents, landfills, acid mines, endocrine disrupting chemicals (EDCs) as well as agricultural or agro-food wastewaters in general that is characterised by high organic content like wineries, olive oil mills and dairy (Abdel-Shafy et al., 1986; Crumpton, 2001; Revitt et al., 2001; Masi et al., 2004).

The importance of CWs mainly depend on the effectiveness in the removal of nutrients (nitrogen and phosphorous) and micropollutants, like persistent organic compounds and elimination of heavy metals (Abdel-Shafy et al., 1994; Masi et al., 2004; Vymazal, 2001). CWs that

Key factors:

- Constructed treatment wetlands have been shown to be a suitable technology for treating wastewater in Egypt.
- Horizontal subsurface flow CWs with intermittent loading have been investigated.
- The CW system proved to be an efficient for treating wastewater in hot climate as it exhibited effective removal of the pollution parameters including pathogenic bacteria.
- Horizontal subsurface flow CWs with intermittent loading can treat domestic wastewater in Egypt up to levels suitable for reuse in agriculture purposes.

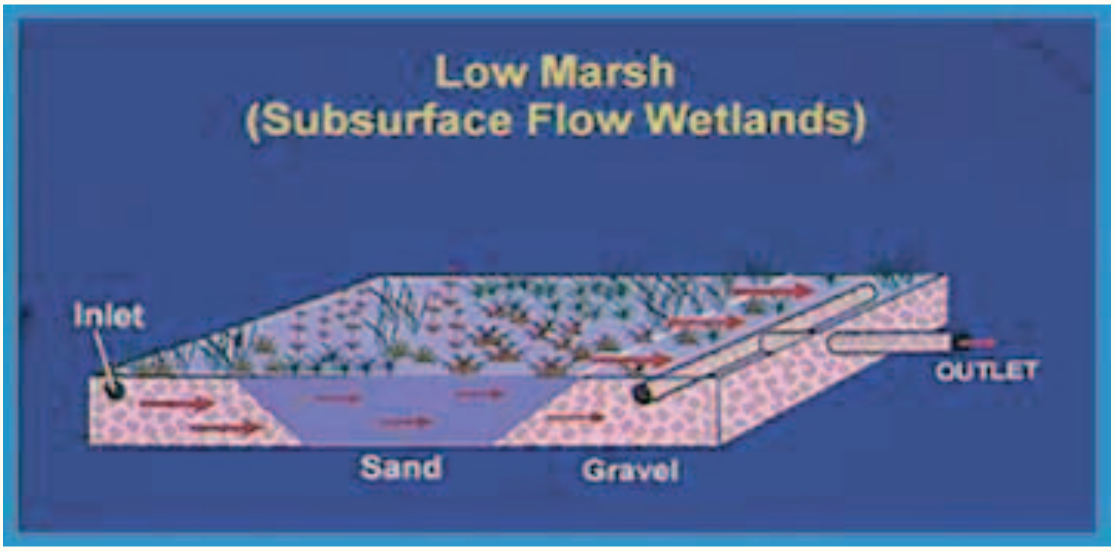

Figure 1: Schematic sketch of a CW bed with HSSF

consist of inclined channels lined with an impermeable geomembrane and filled with flint, can treat wastewater effluents depending on several factors including bed length, depth, gradient, retention time as well as type of aquatic plant and aggregate (Masi et al., 2008, Revitt et al., 2001, WateReuse Research Foundation, 2011).

A field-scale CW with horizontal subsurface flow (HSSF) was established in Ismailia, Egypt, to study the success factors, performance and effects on the characteristics and effluent quality produced by the system in sub-tropical climate areas. The main aim was to evaluate the efficiency of CWs as secondary municipal treatment process in terms of physical, chemical and biological parameters. Different media for the CW main layer were implemented for the purpose of studying their effect on the CW treatment performance.

Materials and Methods

A field-scale CW system with HSSF (Figure 1) was designed and constructed in Ismailia, Egypt, to treat 100 m^3/d of primary treated municipal wastewater. Raw wastewater was subjected to sedimentation followed by a trickling filter, then finally to the CW system. The CW system comprised 6 parallel channels with 2 HSSF beds in series each (Figure 2). The HSSF beds of the 1st stage had different lengths (50 m and 100 m), 2.5 m width and different depths (300 mm and 600 mm). The dimensions of the beds of the 2nd stage were: 40 m length, 2.5 m width and 300 mm depth. The gradient of the channels ranged from 1:20 to 1:50. The flow rate for each channel was controlled by a mean V-notch and was adjusted daily to 20 L/min to each bed. The loading of the CW system was for 18 hours per day, to leave the channels free of wastewater for the rest of the day by night time (i.e. 6 hours), to allow atmospheric oxygen to diffuse into the root zone. The first stage represents the treatment phase which was filled with various types of aggregates (flint gravel, limestone and basalt each with grain size of 4-6 cm). These channels were planted with *Phragmites australis* and *Napier grass* (Figure 3). The channels of the second phase were cultivated with appropriate seasonal crops. Details of design and construction as well as sampling position are summarized in Table 1.

Figure 2: 1st stage HSSF beds, CW system in Ismailia, Egypt

Figure 3: Effluent sampling points at the 6 1st stage HSSF beds

Table 1: Detailed description of the two stages CW system.

Stage	Channel	Type of Plant	Length (m)	Width (m)	Depth (mm)	Type Of Media (4-6 mm)
1	**1**	*Phragmites australis*	100	2.5	600	Flint
	2	*Napier grass*	100	2.5	600	Basalt
	3	*Phragmites australis*	100	2.5	600	Limestone
	4	*Phragmites australis*	100	2.5	300	Flint
	5	*Napier grass*	50	2.5	300	Basalt
	6	Papyrus	50	2.5	300	Limestone
2	**1**	seasonal crops	50	2.5	300	Flint
	2	seasonal crops	40	2.5	300	Basalt
	3	seasonal crops	40	2.5	300	Limestone
	4	seasonal crops	40	2.5	300	Flint
	5	seasonal crops	40	2.5	300	Basalt
	6	seasonal crops	40	2.5	300	Limestone

Wastewater inlet and outlet to the CW were sampled weekly for continuous period of eight months for the determination of the physical, chemical and biological characteristics (total coliform, faecal coliform and faecal streptococci) according to APHA (2005). Sodium, calcium and magnesium were determined in the influent and effluent using Flame Photometer in the same samples of the wastewater. The samples were filtered through Whatmann No.4 and acidified by A.R. nitric acid to a pH value below 2.0 before determination.

Results and Discussion

The physical and chemical characteristics of the primary treated municipal wastewater are given in Table 2. The results show that primary treatment process was efficient. The concentrations of COD, BOD, TSS, and total nitrogen in the influent of the CW system were 220, 126, 195 and 76 mg/L, respectively. The TKN and ammonia nitrogen concentrations were 41 and 23 mg/L. The influent wastewater was anaerobic, no nitrates could be detected and the sulphides concentration were 2.4 mg S/L.

Table 2: Physical and chemical characteristics of the primary treated municipal wastewater, i.e. the influent to the CW system.

Parameters	N	Min.	Max.	Mean value
pH	32	7.1	7.5	7.1 - 7.5
Turbidity	32	160	280	220.1
Dissolved Oxygen (mg/L)	32	0.00	0.20	0.15
COD (mg/L)	32	188	320	220
BOD (mg/L)	32	101	187	126
TKN (mg/L)	32	28	49	41
Ammonia N (mg/L)	32	16	24	23
TN (mg/L)	32	52	89	76
Organic N (mg/L)	32	17	37	28
Nitrates N (mg/L)	32	n.d.	n.d.	n.d.
TSS (mg/L)	32	230	121	195
VSS (mg/L)	32	98	57	79
TDS (mg/L)	32	1176	1788	1474
TR (mg/L)	32	107	188	129
VR (mg/L)	32	87	125	107
Oil & Grease (mg/L)	32	37	67	48
Sulphides S (mg/L)	32	1.2	4.4	2.4

N = number of samples; n.d. = not detected

Table 3: Physical and chemical characteristics of the inlet and outlet of the Ismailia CW system (N = number of samples).*

Sampling position	N	pH	DO (mg/L)	TSS (mg/L)	BOD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)
Inlet	25	7.1 - 7.5	0.15	195	126	23	0.00
Outlet short bed (50 m)	25	7.1 - 7.5	1.90	30	25	17	0.51
Outlet long bed (100 m)**	25	7.1 - 7.5	3.90	20	14	12	0.94
Outlet long bed (100 m)***	25	7.1 - 7.5	3.15	22	15	12	0.92
Crop bed (40 m)	25	7.1 - 7.5	4.19	12	11	10	2.16

* presented values are the averages of all studied samples.
** Channel planted with *Phragmites australis*.
*** Channel planted with *Napier grass*.

Table 4: Total coliform, faecal coliform and faecal streptococci contamination in the inlet and outlet of the Ismailia CW system (mean values, N = number of samples).

Sampling position	N	Total coliforms (10^3 CFU/mL)	Faecal coliforms (10^3 CFU/mL)	Faecal streptococci (10^3 CFU/mL)
Inlet	21	497	129	28.3
Outlet planted bed	21	34.6	6.91	0.0995
Outlet crop bed	21	1.53	0.080	0.0994
Outlet non-vegetated bed	21	4.6	0.091	0.029

The physical and chemical characteristics of the municipal wastewater inlet and outlet of the variable CW channels are presented in Table 3 as mean values. The pH values showed no variation in the long or short channel. This indicates a buffering capacity of the system. For the dissolved oxygen (DO) gradual increase towards the outlet could be observed. The effluent from the short channel had lower DO (1.90 mg/L) in correlation to the effluent from the long one (3.91 mg/L) that planted with *Phragmites australis*, and (3.15 mg/L) that planted with *Napier grass*. The value of the D.O. increased to (4.19 mg/L) in the outlet of the crop channel.

The removal efficiencies calculated from Table 3 for total suspended solids (TSS) have been 84.6 %, 89.7 %, 88.7 % and 93.8 % for short channel, Phragmites long channel, Napier long channel and crop channel respectively. BOD removal was 80.2 % for the short channel, 88.9 % for both long channels, and 92.1 % for crop channel. Remarkable improvement was achieved in terms of the ammonium and nitrate nitrogen. The short beds showed little changes for NH_4-N (26.1 % removal). However, better improvement was recorded in the effluent of the long beds as well as the crop channels (47.8 % and 56.5 % respectively). The nitrate-nitrogen (NO_3-N) exhibited increase from zero to 0.51 mg/L in the short bed outlet then slight improvement was achieved in long channels. Further increased was reached in the effluent of the crop channel (2.16 mg/L).

Furthermore, the CW system was effective in eliminating pathogenic bacteria as indicted by total coliforms, faecal coliforms and faecal streptococci (Table 4). The die-off rates of microbial groups were calculated for the determination of the removal rates. The results indicate that the mean bacterial count is the highest die-off rates in all the studied cases. However, increasing the bed length showed no importance effect on the removal of bacterial indicators. The general observation shows that effective removal of indicator bacteria, namely total coliform, faecal coliform and faecal streptococci, was achieved in all cases due to the long retention time. Higher removal was achieved in the second stage for the same reason; namely longer duration time of wastewater in the CW.

Concentrations of Na, Ca and Mg in the influent and effluent of the 6 CW channels are given in Table 5. The results indicated that the level of the studied metals increased in the effluent. This can be attributed to the partial evaporation of the wastewater on the surface of the CW during the long retention time of the treatment process. It is worth noting that the level of Ca and to less extend Mg in the limestone channels numbers 3 and 6 exhibited slight higher increase as indication of slow release of Ca and Mg from the limestone media of these channels. On the contrary, the other channels; namely flint and basalt; did not exhibit any release of Na, Ca or Mg as indication that these materials are stable and inert with wastewater. However, flint was

Table 5 : Concentrations of Na, Ca and Mg in the municipal wastewater in the inlet and outlet of the Ismailia CW system (N = number of samples, in mg/L).

Channel	N	Na		Ca		Mg	
		IN	OUT	IN	OUT	IN	OUT
1	16	56	63	56	59	44	55
2	16	68	70	68	75	50	54
3	16	65	80	65	79	50	68
4	16	60	74	66	70	42	60
5	16	63	74	62	70	49	55
6	16	62	69	67	81	43	59

Table 6: Effluent concentrations of the Ismailia CW system and Egyptian regulation* for wastewater reuse

Parameter	Unit	1st group Primary treated water	2nd group Secondary treated water	3rd group Advanced treated water	Effluent of the CW system
BOD_5	mg/L	300	40	20	11 - 25
COD (dichromate)	mg/L	600	80	40	28 - 76
TSS	mg/L	350	40	20	12 - 30
Oil and grease	mg/L	Not limited	10	5	3 - 5
Number of cells or eggs of Nematodes	Counts/L	5	1	1	-
E.Coli	100/mL	Not limited	1000	100	< 100
TDS	mg/L	2500	2000	2000	998 - 1763
Na absorption ratio	%	25	20	20	12 - 19
Cl-	mg/L	350	300	300	84 - 121
B	mg/L	5	3	3	2 - 3

* The permissible limits for irrigation according to the Egyptian Law 48, No.61-63, Permissible values and Law of the Environmental Protection (1994); updated by No.44, (2000).

circular or curved shape, but basalt was sharp edged. This means that flint has an advantage over the basalt for supporting larger surface area.

The average final effluent concentrations of BOD_5, COD, TSS, oil & grease, TDS, chloride and Boron of the CW system ranged from 11 - 25, 28 - 76, 12 - 30, 3 - 5, 998 - 1763, 84 – 121, and 2 – 3 mg/L, respectively (Table 6). The calculated Na absorption ratio ranged from 12 - 19 and the E.Coli count were less than 100 MPN/100 mL. Such quality of treated effluent is accepted as “3rd group advanced treated water” classified as “Class Excellent” according to the Egyptian irrigation regulation (EEAA, 2000).

The overall results reveal that a CW system with HSSF and intermittent loading is capable of treating the domestic wastewater in Egypt up to acceptable environmental level suitable for irrigating agriculture products where the crops are not intended for immediate human consumption without further processing. The treatment process provides effluent appropriate for crop irrigation with acceptable level of nitrogen as NH_4-N (7.8 mg/L) and NO_3-N (2.2 mg/L) and dissolved oxygen (3.8 mg/L) as good indicator of adequate treatment. Slight release of Ca from the channels using limestone as filter media was confirmed.

Conclusions

The following conclusions can be drawn:

1. Constructed wetlands (CWs) with horizontal subsurface flow and intermittent loading showed efficient treatment of primary treated municipal wastewater.
2. Removal efficiencies for BOD_5, total suspended solids and ammoniacal-N were 90 %, 93 % and 54 to 70 %, respectively.
3. Effective elimination of the indicator bacteria (total coliforms, faecal coliforms and faecal streptococci) was achieved. However, increasing the bed length showed no importance effect on the removal of bacterial indicators.

4. Longer beds up to 100 m were more efficient than shorter beds (50 m) as indicated by the quality of the effluent.
5. Beds planted with papyrus showed similar treatment efficiency as beds planted with *Phragmites australis* and *Napier grass*.
6. Concentration of Na, Ca and Mg is slightly increased in the effluent due to the high evaporation rate in Egypt's hot climate. In addition, release of Ca and Mg from the limestone channels may occur. Therefore, it is recommended to avoid using limestone as filter media in CWs.
7. Using flint as filter media in CWs has advantage over the basalt for supporting larger surface area.
8. The overall results reveal that the CW system is capable of treating the domestic wastewater up to an level suitable for irrigating agriculture products where the crops are not intended for immediate human consumption without further processing.

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Sludge Treatment in Reed Beds Systems – Development, design, experiences

Sludge treatment in reed bed systems is a thoroughly tested method. Experience shows that the method is an environmentally friendly and cost efficient sludge treatment

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Abstract

There are important differences in the environmental perspectives and costs involved in mechanical sludge dewatering followed by disposal on agricultural land compared to reed bed sludge treatment. The effect on the environment of the operation of a Sludge Treatment in Reed Beds system is seen as quite limited compared to traditional sludge treatment systems such as mechanical dewatering and drying, with their accompanying use of chemicals; incineration; direct deposition on landfill sites, etc. After reduction, dewatering, and mineralisation in a reed bed sludge treatment system, sludge with a solids content of 0.5-3% can attain depending on the sludge quality dry solids content of up to 20-40%. In addition, mineralisation removes up to 25% of the organic matter in the sludge. The quality of the final product in sludge reed beds with respect to pathogen removal and mineralisation of hazardous organic compounds after treatment make it possible to recycle the biosolids to agriculture.

Loading - operational strategy

The operation of a reed bed system may be divided into a number of periods relating to the lifetime of the system. A system generally runs for a total of at least 30 years; this period is divided into two or three 8-12 year phases. Each phase consists of commissioning, normal loading, emptying and re-establishment of the system. Full Operation following the commissioning of the plant operations means that the yearly loading is increased to the sludge production from the wastewater treatment plant corresponding to the maximum capacity (tons dry solid/year) of the sludge reed bed system. The loading strategy involves assigning an individual quota to each individual basin. This quota is a sludge volume which generally increases throughout the entire period of operation until emptying, but it may also vary or even decrease to zero for periods. The length of the loading periods and rest periods between loadings depends on the age of the system/basin, the dry solid content, the thickness of the sludge residue and the intensity of partial loadings during the period of loading. On a daily basis, the basins are subjected to a loading of 1-3 partial loadings of approx. 1 hour for a short period (from a few days to a maximum of 2 weeks during commissioning) until the quota is used and loading switches to the next basin.

Mechanical sludge dewatering involves conditioning with chemicals, usually in connection with the dewatering process itself. Either organic polyelectrolytes or inorganic conditioning substances are used (Table 1). In a sludge reed bed system the dewatering process is governed

Key factors:

- Long-term experience (> 20 years) exists for Sludge Treatment Reed Bed Systems
- Operation is reliable and flexible, with very low operating costs, low energy consumption and no use of chemicals
- The areal loading rate is set to maximum 30 - 60 kg dry solid/m²/year after commissioning
- Regardless of sludge type and the size of sludge production, a minimum of 8 – 10 basins are necessary
- The basin depth must be no less than 1.7-1.8 m from the filter surface to the crown edge
- Beds are usually emptied every 8-10 years, a final dry solids content of 20 – 40 % can be achieved before emptying the beds.
- Experience shows that final sludge quality allows recycling the biosolids on agricultural land.

Table 1: Dry solid content related to dewatering method

Dewatering method	Centrifuge	Filter Belt Press	Filter Press	Traditional Sludge Bed	Sludge Reed Beds Systems
% Dry Solid (DS)	15-20	24 (15-20)	32	10	20 – 40

by the sludge quality, the climate, the wind, the gravity and the vegetation. The water in sludge with a dry solid content of 5% can be divided into pore water (66.7%), capillary water (25%), adsorption water and structurally bound water (8.3%). Dewatering the pore water concentrates the sludge to a dry solid content of about 15%. Further dewatering by removal of the capillary water concentrates the sludge up to a dry solid content of about 50%. The remainder of the water in the sludge may be removed by drying. Reed beds have been used for sludge reduction in Denmark and Europe since 1988 when the first sludge processing system was introduced. Long-term sludge reduction takes place in reed-planted basins, partly due to dewatering (draining, evapotranspiration) and partly due to mineralisation of the organic matter in the sludge. From waste-water treatment plants the sludge is pumped onto the basin surface/sludge residue. The dewatering phase thus results in the dry solid content of the sludge remaining on the basin surface as sludge residue, whereas the majority of its water content continues to flow vertically through the sludge residue and filter layer. The sludge residue water content is further reduced through evapotranspiration. In addition to dewatering, the organic matter in the sludge is mineralised, thereby minimising the sludge volume. The overall sludge volume reduction occurs without the use of chemicals and involves only a very low level of energy consumption for pumping sludge and reject water. Experience from the reference plants is that this type of system is capable of treating many types of sludge with a dry solid of approx. 0.5 to approx. 3-5%.

The system runs at full capacity for subsequent 10-year periods of operation, including periods of emptying. Normally, emptying is planned to start in year 8 and is completed in year 12 of each operation period. In order to meet the requirements of capacity for a 10-year treatment period of operation, as well as dewatering of the sludge residue to a dry matter content of approx. 20 - 40% depending on the sludge quality (Table 1), the following dimensioning standards are recommended. Dimensioning of the sludge reed bed systems is based on the following factors: Sludge production (tons of dry solid per year), sludge quality, sludge type and climate.

Sludge quality

The physical quality of the sludge changes at different stages of the dewatering process. The content of fat (max 5000 mg/kg DS) in the sludge, as well as the form of production (e.g. low sludge age, concentration, pre-dewatering using polymer, mesophile or thermophile digestion) are of importance to the sludge dewatering capacity and to the final dimensioning and number of basins. In addition to the sludge dewatering capacity, loss on ignition is a factor in the dimensioning. As a rule, a loss on ignition of 50-65% is recommended.

Areal loading rate

The areal loading rate is determined in relation to the sludge type, climate and must take emptying into account. With regard to loading of surplus activated sludge, the areal loading rate is set to maximum 30 - 60 kg dry solid/m²/year after commissioning. With regard to sludge types, e.g. from digesters (mesophile, thermophile), sludge with a high fat content, or sludge with a low sludge age (< 20 days), an area loading rate of maximum 30 - 50 kg DS/m²/year is recommended.

Number of basins

In relation to a 10-year period of operation, dewatering, vegetation and mineralisation, it is necessary to operate the basins with alternating periods of loading and resting. Regardless of sludge type and the size of sludge production, a minimum of 8 – 10 basins are necessary, in order to achieve the required ratio between loading and resting periods. Experience shows that systems with too few basins, i.e. fewer than 8, often run into operating problems, including very short periods of operation until emptying with poorly dewatered sludge residues and poor mineralisation. The basin depth must be no less than 1.70-1.80 m from the filter surface to the crown edge. The basins must have a sufficiently high freeboard to allow for 1.50-1.60 m of sludge residue accumulation. Basin capacity must also allow for increased loadings during the emptying phase of e.g. 2-4 years until all basins have been emptied.

Figure 1: Kolding Sludge Reed Bed System for 125000 PE (September 2000)

System description and design

Sludge from the wastewater treatment plant the sludge may be pumped out from the active sludge plant, final settling tanks, concentration tanks or digesters in batches into the basins.

Filter design and reeds

Each basin forms a unit consisting of a membrane, filter, sludge loading system and reject water and aeration system. (Figure 1). The total filter height is approx. 0.55 0.60 m before sludge loading. The reeds contribute to dewatering the sludge via increased evapotranspiration from the sludge residue and by mechanically influencing the sludge residue and filter. Finally, the presence of reeds contributes to the mineralisation of the organic solid in the sludge.

Sludge loading, reject water and aeration systems

Loading must be planned in such a way as not to inhibit development of the reeds and to prevent the sludge residue from growing so fast that the reeds cannot keep up horizontally and vertically. It is not recommended to apply a 100% loading rate immediately after planting. Pressure pipes are installed to each basin, terminating in a distribution system to distribute the sludge. An important detail is to ensure that the sludge is pumped out in a way which creates a uniform and even sludge load across the entire filter area. The reject water system has two functions. The first is to collect and return the filtered water to the wastewater treatment plant. The second function is to aerate the filter and the sludge residue.

Environmental impact assessment

Sludge treatment in reed bed systems is a thoroughly tested method with a number of proven advantages. Experience shows that the method is an environmentally friendly and cost efficient sludge treatment. It uses very little energy and no chemicals, has a minimum of CO_2-emissions, provides a good working environment, and reduces sludge residue significantly. The European Union Water Framework Directive (2000/60/EC) calling for cleaner discharges from our waste water treatment facilities can result in more sludge, due to the improved treatment; however, managing sludge is rather costly. In countries like Denmark, Germany, France, Spain and Sweden sludge treatment in Reed Bed Systems are a common and a well-proven method during the last 20-24 years (De Maeseneer, 1997, Giraldi et al., 2008; Lienard et al., 1995; Nielsen, 2003a, 2003b, 2008; Pempkowiak and Obarska-Pemkowiak, 2002; Obarska-Pemkowiak et al., 2003; Peruzzi et al., 2007; Troesch et al., 2008a, 2008b; Uggetti et al., 2009a, 2009b; Zwara and Obarska-Pemkowiak, 2000).

Better working environment

When the system is setup, there is no contact with the sludge. There is no noise from the system as there is from many other types of treatment systems, and there is no odour from it either. The system works effectively to reduce pathogenic bacteria like Salmonella, Enterococci and E. coli, thus making it a lot safer to be on site.

A cost effective system

The man-hours needed to run the system are fewer than with traditional methods, and require only a weekly control-visit to the site of about one to two hours. Sludge treatment reed bed systems utilise the forces of nature to reduce and treat sludge. The only appreciable power consumption is by the pumps used to transport sludge and reject water. This means that the reed bed system uses much less power than other systems. Transport costs will be reduced substantially, while the volume of sludge can be reduced to approximately 1.5-2.5 % of its original volume. The sludge will be of a better quality and suited for use on agricultural land. This offers more opportunities for disposing of the sludge after treatment.

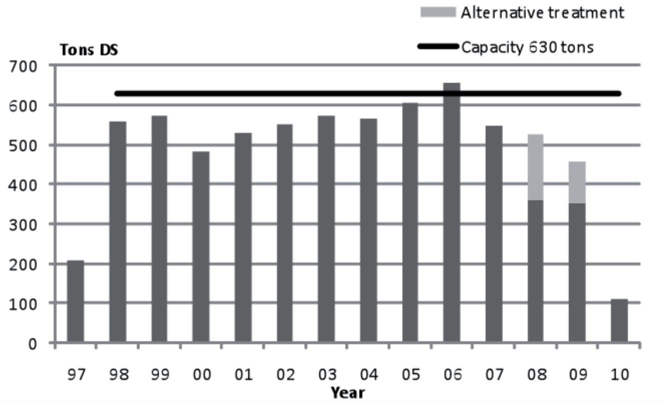
No chemicals needed

Sludge treatment in Reed Bed Systems uses no chemicals in the dewatering process. This means a considerable improvement in the working environment along with a reduction of the chemical residue in the treated waste water passing into the environment.

Good options for recycling

The content of substances in sludge that are foreign to the environment can be reduced to such a degree that the sludge conforms to the limits and norms for deposition on agricultural land. Treatment in a sludge reed bed system was shown to be effective at treating raw sludge containing large amounts of pathogenic bacteria including Salmonella, Enterococci and E. Coli. As a general rule, pathogenic bacteria that are excreted and end in an alien environment only live for a short period of time, depending upon various environmental factors and the bacteria's own characteristics.

The sludge (approximately 0.5-0.8% DS) loaded into the individual basins contained a large number of bacteria. Salmonella, Enterococci and E. Coli were found in the sludge in the following quantities: 10-300 per 100 g (wet weight), 7000 – 250000 CFU/g (wet weight) and 800 - 10000.10^3 CFU/100 g (wet weight), respectively. Analysis of the reduction in pathogens in the sludge residue through a period of 1-4 months after the last loading from the Helsinge sludge reed bed system (basin no. 8) indicated that the pathogen content was reduced to <2 per 100g (Salmonella), <10 CFU/g (Enterococci) and <200 number/100 g (E. Coli). For Enterococci and E. Coli the reduction was approximately log 5 and log 6-7, respectively (Nielsen, 2007).



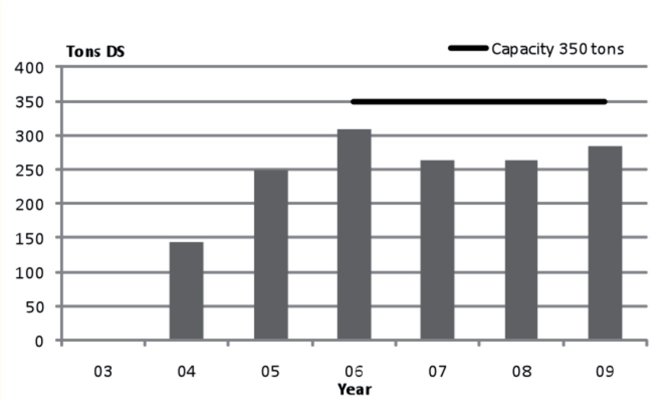


Figure 2: Sludge production and sludge load (left: Helsinge, right: Nordborg)

Mineralisation of Linear Alkylbenzene Sulphonates (LAS) and Nonylphenolethoxylates (NPE), which may be detrimental to the environment, if spread in large concentrations, in mesophilic digested sludge was observed during a 9 month monitoring programme. The reduction was 98% for LAS and 93% NPE. After the treatment of sludge, recycling options are good, particularly in agriculture. The sludge quality is cleaner and more adaptable in the natural cycle than mechanically dewatered sludge (Nielsen, 2005).

Case Studies

Experience from a large number of systems in many countries treating a whole range of sludge types has shown the efficiency of the method, which can be demonstrated in selected cases.

Helsinge sludge reed bed system

Sludge production from the Helsinge wastewater treatment plant (42000 PE) consists of activated sludge directly from the activated sludge plant and activated sludge from final settling tanks. This production (tons dry solids) constitutes approximately 66% of the loading of the sludge reed bed system. The remaining 33% of the sludge production consists of concentrated anaerobic activated sludge from 4 smaller wastewater treatment plants. The type of sludge was mixed in each delivery before being added to the reed bed system. The sludge was pumped via a mixing tank and a valve building, where the sludge flow and dry solids were registered before being led to the respective basins. Total sludge production has increased during the period from 1997-2005 from approx. 209 tons of dry solid annually to approx. 606 tons of dry solid annually. Annual sludge production amounts to 550 - 600 TDS (Figure 2, left).

The Helsinge Sludge Reed Bed System is a Danish system that was established in 1996 and consists of 10 basins, each having an area of 1050 m^2 at the filter surface. The system has a capacity of 630 TDS per year and a maximum area loading rate of 60 kg DS/m^2/year. The annual load rate (tons dry solids) of the Helsinge sludge reed bed system during the period from start of operations and to 2010 has been in the order of 90 % of capacity. From 2000 to 2005, loading has increased by approx. 130 tons dry solids. The loading regime of the system consists of applications of approximately 130-150 m^3 of sludge (mixed sludge) being applied once or twice daily to the plant's basins in relation to individual basins' loading quota and capacity, with the feed concentration being approximately. 0.5-0.8 % DS. Each basin was subjected to a loading quota of 1,500 m^3 over a period of approximately 6-8 days. Loading was followed by 45-65 rest days.

After commissioning the individual basins were subjected to an average loading rate of approximately 55-65 TDS per year, resulting in an average area-specific loading rate of 55-64kg DS/m^2/year. Because of the increasing sludge production and emptying of two basins yearly, the area-specific loading rate has increased from approximately 46 kg DS/m^2/year in 2000 to 68-88 kg DS/m^2/year in 2007. The sludge residue height status in basin 1 in relation to time and area-specific loading rate (kg dry solid/m^2/year) was calculated on the basis of scale pole readings. The sludge residue height increase from 1998 to 2005 was approx. 1.20 m (basin no. 1), and the total sludge residue height by April 2008 was approximately 1.60m (Figure 4). Helsinge sludge reed bed system has been emptied over a 4-year period (2005-2008), with 2-3 out of 10 basins selected for emptying per year. Capacity during the emptying period was maintained at 630 tons of dry solids per year. The last 3 basins were emptied in 2008.

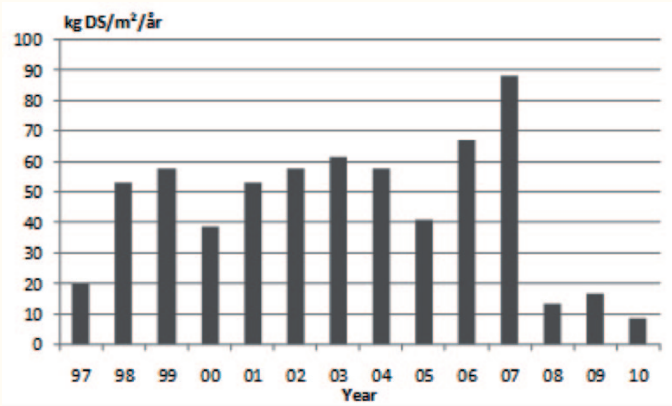


Figure 3 Helsinge Sludge Reed Bed System (basin no.1) Average area loading rate (kg DS/m^2/year)

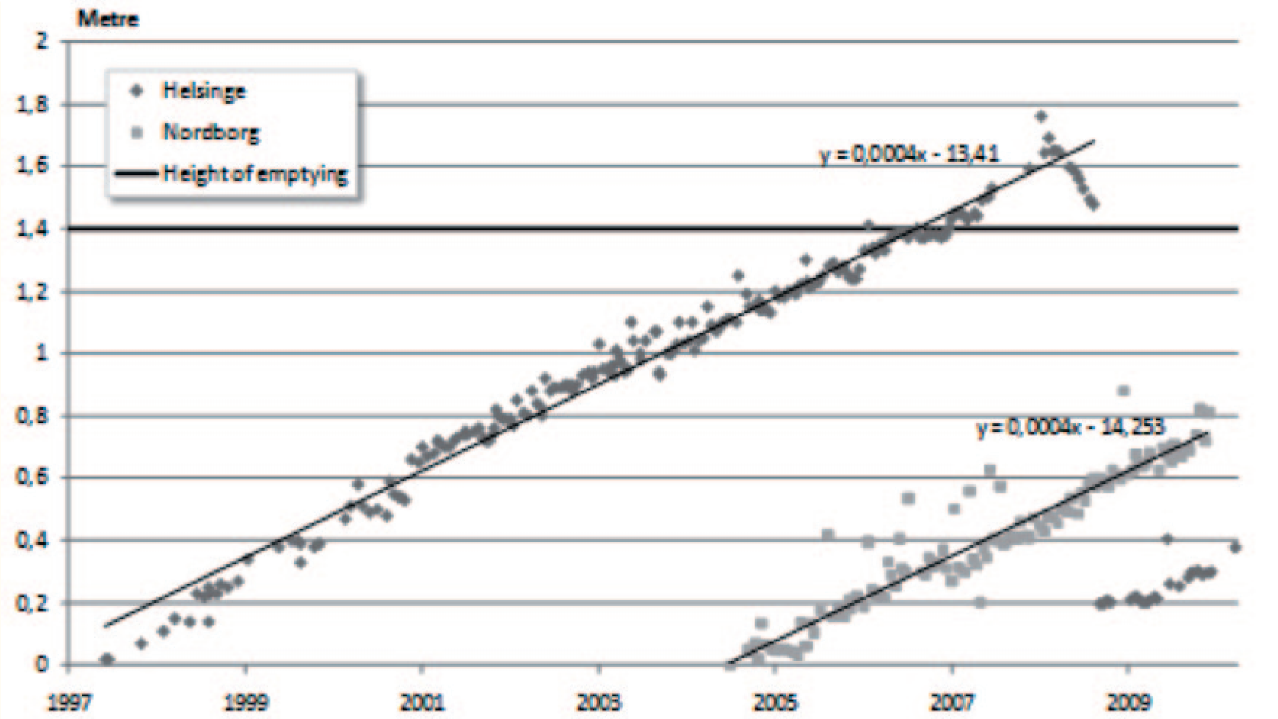


Figure 4 Sludge residue increment

Sludge residue quality

The quality of the sludge residue in the Helsinge sludge reed bed system met valid statutory order criteria with regard to heavy metals and hazardous organic compounds for use on agricultural land after ten years of biological treatment in the sludge reed bed system. The dry solids content in the sludge residue was up to 35.5%. Nitrogen and Phosphorus contents were on the order of 22-28 and 30 g/kg DS, respectively.

Emptying, Recycling and Regeneration

The plan was to empty the Helsinge over a 5-year period (2005-2008) with 2-3 out of 10 basins selected for emptying per year. The two basins selected for emptying are excluded from the loading plan approximately ½-1 year before emptying, and have a reduced load the first year after emptying. Capacity during the emptying period (5 years) was maintained at 630 tons of dry solids per year despite reduction of the basin number during the emptying period. The loading of individual basins increased from approximately 55 to 88 kg DS/m^2/year, as system loading during the emptying period applies to only 6-8 basins. From each of the basins approximately 1000-1400 tons of sludge residue were removed. The sludge residue was deposited on approx. 158-170 ha taking into consideration Phosphorus content with max. 90 kg P/ha for individual areas every third year. Maintaining full capacity during emptying is only possible provided that the basins are re-established after emptying with sufficient regeneration of vegetation, and provided that the loading rate is adapted to vegetation growth. Helsinge sludge reed bed system has generally had a satisfactory rate of regeneration after emptying in both 2005 and 2006, so that re-planting basins has only been necessary in few of the 10 basins.

Nordborg sludge reed bed system

Nordborg Sludge Reed Bed System (dimensioned to process wastewater from 18000 PE.) is another Danish system with 10 basins. The system was established with reeds in 2003 and has a capacity of 350 TDS per year. Each of the basins has an area of approx. 705 m^2 at the filter surface and a maximum area-loading rate of 50 kg DS/m^2/year. Sludge production from the WWTP consists of activated sludge (SAS) directly from the activated sludge plant and digested sludge from a mesophil digester. The two sludge types are mixed before being added to the Reed Bed System. 90 – 120 m^3 (approx. 0.5 % DS.) of SAS is mixed with 3-6 m^3 of digested sludge (approx. 2-3 % DS). The Annual sludge production amounts to 250 - 300 TDS (Figure 2, right).

Finally, the batch is diluted with effluent from the WWTP to a final volume of 140-160 m^3. The system's loading regime consists of applications of approximately 140-160 m^3 of sludge (approx. 0.6-08 % DS) once daily. From 2006 on, each basin was subjected to a loading quota of 600 m^3 over a period of approximately 4 days. Loading was followed by a 36-64 days' rest period. The area-specific loading rate was between 36-44 kg DS/m^2/year in period 2004 to 2009. The sludge residue height increased in the period from 2004 to 2009 by 0.83 m (Figure 4). The plan is to empty Nordborg sludge reed bed system over a 4-year period (2011 2014), with 2-3 out of 10 basins selected for emptying per year. Capacity during the emptying period will be maintained at 350 tons of dry

Figure 5 Nordborg Sludge Reed Bed Systems

Figure 6 Trials for Hanningfield Sludge Reed Bed Systems (June 2009)

solids per year.

Hanningfield sludge reed bed system

Hanningfield Water Treatment Work is supplied with raw water from Hanningfield Reservoir (354 ha) with a water production of 150 million litres/day for 1.5 million people. The Hanningfield (England) Sludge Reed Bed System is a new system treating water works sludge. The use of reed bed systems not only reduces the capital and operating cost, but also provides the site with an environmentally-friendly operational area. Therefore, 6 trials bed (20 m^2 each) have been monitored (2008 – 2010) to examine the dewatering processes of the liquid sludge produced from the water treatment process, which includes treatment with iron sulphate to help dirt particles to coagulate. It is possible to get the vegetation to grow in ferric sludge, where the pH was measured to 7.7. It has not been necessary to use fertilizer. The influence of the loading programs (15-50 kg DS/m^2/year) was tested. It is possible to drain and treat ferric sludge (approximately 300000 mg Fe/kg DS). Generally the dewatering profile is a peak with a maximum over 0.010 – 0.025 l/sec/m^2. The times for dewatering of 6-12 m^3 are approximately 15 hours and over 90 % of the load is dewatered in that period. Even for the basins which had been loaded with 12 m^3 each day for 4-6 days. The dry solid (0.13 - 0.20 %) in the sludge has been concentrated approximately 200 times. The dewatering phase results in ferric sludge with 30-40% dry solid which cracks up very quickly. In spite of the different loading programs, volume reduction is very high at over 99 %. Based on a total load of 1275 tons/year, the test results lead to a design with a loading rate of 30 kg DS/m^2/year, a red bed area of 42500 m^2, and 16 parallel basins.

Conclusion

This paper presents experience and know-how from a 24-year period (1988-2012), primarily with references from Denmark. The accumulation of knowledge, guidelines for dimensioning and operations, and descriptions are based on experience from more than 10 sludge reed bed systems, mainly loaded with activated sludge residue. The Sludge Treatment Reed Bed System is a long-term sludge solution, and the systems are built to treat sludge for an average operative period of 10 years. Experience shows that operation is reliable and flexible, with very low operating costs, low energy consumption, no use of chemicals (polymers) for dewatering, an improved working environment and the freeing-up of waste water treatment capacity. The basins in Helsinge sludge reed bed system have, since 1998, been subjected to an average loading rate of approx. 55 tons DS per year, resulting in an average area-specific loading rate of 55-64 kg DS/m^2/year. The sludge residue height in relation to time and area-specific loading rate increased from 1998 to 2008 was approximately 1.60 m. or approximately 0.16 m per year. It has been possible to maintain full capacity during emptying because the basins are re-established after emptying with sufficient regeneration of vegetation.

It has thus not been necessary to re-plant basins. Experience shows that good mineralisation of hazardous organic compounds, good reduction of pathogenic microorganisms and a final dry solids content of 20 - 40% can be achieved. With respect to heavy metals, hazardous organic compounds and pathogen removal 10 years of treatment make it possible to recycle the biosolids on agricultural land.

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