Chapter 14
Constructed Wetlands Treating Municipal and Agricultural Wastewater – An Overview for Flanders, Belgium

Hannele Auvinen, Gijs Du Laing, Erik Meers, and Diederik P.L. Rousseau

Abstract Flanders is one of the most populated regions in Europe where agriculture is large-scale and intensive. It is therefore challenged by high nutrient loads which deteriorate the surface water quality through direct discharge from wastewater treatment plants and through runoff from agricultural fields. According to our survey, constructed wetlands are in Flanders mainly used to treat domestic and agricultural wastewater in rural areas. The use of constructed wetlands as individual treatment systems has increased in the last years due to the obligation of wastewater treatment at remotely located households. In this overview, the performance of constructed wetlands treating municipal wastewater and manure treatment wastewater is analyzed. In general, the constructed wetlands studied were found to meet the limits set in the Flemish legislation for wastewater effluent quality. Many of the wetlands treating municipal wastewater are, however, dealing with high nitrogen loading which results in low total nitrogen removal efficiency. Also the phosphorus removal capacity in these wetlands was found to be limited. Therefore, these wetlands do not majorly decrease the nutrient discharge to the environment. The constructed wetlands treating manure treatment wastewater are, on the contrary, over-dimensioned and thus able to achieve excellent nutrient removal efficiency.

Keywords Nitrogen • Phosphorus • Efficiency • Domestic wastewater • Manure

---

H. Auvinen
Laboratory of Industrial Water and Ecotechnology, Ghent University Campus Kortrijk, Graaf Karel de Goedelaan 5, 8500 Kortrijk, Belgium

Laboratory of Analytical Chemistry and Applied Ecochemistry, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

G. Du Laing • E. Meers
Laboratory of Analytical Chemistry and Applied Ecochemistry, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

D.P.L. Rousseau (✉)
Laboratory of Industrial Water and Ecotechnology, Ghent University Campus Kortrijk, Graaf Karel de Goedelaan 5, 8500 Kortrijk, Belgium
e-mail: Diederik.Rousseau@UGent.be

© Springer International Publishing Switzerland 2016

J. Vymazal (ed.), *Natural and Constructed Wetlands*,
DOI 10.1007/978-3-319-38927-1_14

14.1 Introduction

14.1.1 Treatment of Municipal Wastewater

Flanders, the northern region of Belgium, has a total surface area of 13,522 km^2, and is inhabited by approximately 6.2 million people (Belgian Federal Government 2010). By the end of 2014, 86 % of the households in Flanders were connected to a sewer network, the connection rate being higher in urban areas than rural areas, and over 94 % of the collected wastewater was effectively treated (VMM 2015). For the other households, there has been uncertainty for many years whether or not they will still be connected or will have to take own responsibility in treating wastewater. This issue has been solved in the period 2006–2008 by the elaboration of zonation plans. For this, the territory has been divided into three zones: where a sewer network already exists, where it is planned to be built and where treatment of wastewater is the responsibility of the individual households.

The drinking water companies are responsible for treatment of wastewater collected in the sewer systems. They co-operate with Aquafin N.V. and municipalities which organize the collection and treatment in practice. In case a household is remotely located and no sewer system is available and planned to be built, an individual small-scale treatment system must be installed. These systems must be selected from a list of certified installations according to a Belgian standard BENOR which is based on European standard EN 12566/3 (Certipro 2015). This list contains constructed wetlands among others.

Small-scale treatment systems for the treatment of municipal wastewater only have to meet a COD standard of 125 mg/L and an influent load reduction of at least 90 %; a BOD_5 standard of 25 mg/L in combination with an influent load reduction of 75 %; and a TSS standard of 35 mg/L (500–2000 IE) or 60 mg/L (<500 IE) in combination with an influent load reduction of 70 %. For plant-based systems, there is even an exception in the sense that they are exempted from these standards in case the temperature drops below 5 °C, indicating an (unwarranted) lack of confidence in constructed wetlands (VLAREM 2016). There are no nutrient limitations for small-scale treatment systems treating municipal wastewater.

14.1.2 Treatment of Agricultural Wastewater

Farming in Flanders is large-scale and intensive, which is linked to high consumption of fertilizers (both inorganic and manure) and deterioration of soil and water quality (EU 2014). High concentrations of nitrates have been (and are still being) measured in groundwater and surface waters (MIRA 2014), and therefore, the whole of Flanders is classified as Nitrate Vulnerable Zone as described in the Nitrates Directive (EU, 1991[a]). Tertiary treatment of agricultural wastewater originating from pig manure processing activities has developed in Flanders over the last decade to decrease the nutrient loading to the surface waters.

Meers et al. (2008) described for the first time the successful application of a pilot scale pilot installation of constructed wetlands, designed for the downstream processing of the liquid fraction coming from physical separation of manure (centrifuge, sieve band press or fan press) and pre-treated by biological processing (nitrification / denitrification). The pilot-scale installation was initially designed for 1000 t/year of pig manure processing down to dischargeable concentrations. After proof-of-principle at this pilot installation, the technique was commercially rolled out as the "Innova Manure" system. Currently multiple treatment wetlands have been constructed in Flanders, with a capacity treating of 70,000 t/year of animal manure. The wetland systems in actuality form a green buffer around industrial pig farming and manure processing facilities (nitrification/denitrification tanks) and perform additional ecoservices, such as establishing an enhanced biodiversity (Boets et al. 2011). The effluent standards which all manure treatment CWs need to meet are the same as those for municipal wastewater treatment systems of 2000–10,000 I.E.: 125 mg COD/L, 25 mg BOD_5/L, 15 mg TN/L, 2 TP mg/L and 35 mg TSS/L.

14.2 A Database on Constructed Wetlands in Flanders

14.2.1 Data Collection

An elaborate review on constructed wetlands in Flanders has been published about a decade ago (Rousseau et al. 2004) with a state-of-the art *anno* 2004. To create an updated database of constructed wetlands in Flanders, organizations active in wastewater treatment were contacted in the course of 2014. These included both government-related organizations (Aquafin N.V. and the Flemish Land Agency VLM) and private wetland constructors. The latter were found via online queries.

As a first step, data on the location, size and type of wetland and treated wastewater were collected. Secondly, data on treatment performance were collected. Because there is no monitoring obligation for such small treatment plants, data are quite scarce.

For this chapter we processed the data from the Aquafin operated wetlands ($n = 35$) and from six manure treatment wetlands ("Innova Manure"). The Aquafin operated wetlands are monitored at least 12 times per year for common water parameters, i.e. chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), Kjeldahl nitrogen (KjN), total nitrogen (TN), total phosphorus (TP). These data with the flow data are publicly available at http://geoloket.vmm.be/ Geoviews/map.phtml, which is regularly updated by the Flemish Environment Agency VMM. The "Innova Manure" wetlands are also monitored on a monthly basis. These systems are monitored by an external company (i.e. not the manure processing installation or pig farmer themselves) at several locations within the wetland system, from inlet to discharge. The data from the "Innova Manure" wetland systems were provided by the constructors.

These systems are monitored for ingoing and outgoing concentrations of COD, TN and TP.

14.2.2 Data Processing and Analysis

The raw water quality data from the year 2005 (or any later start-up of the wetland) until the end of 2014 (or prior shutdown of the wetland) was processed for the data analysis. The data in the Geoloket are based on time- or flow-dependent sampling and in some cases the samples are taken as grab samples. The samples at the manure treatment installations are grab samples.

Based on these data, the following characteristics were calculated as averages from all data points during the surveillance period:

- Removal efficiencies (%), based on influent and effluent concentrations
- Histogram represents the distribution of the probability for a sample to be below a certain value (e.g. the 90-percentile means that 90 % of all samples in the database have a concentration below the indicated concentration, 10 % have a concentration above the indicated concentration)
- Areal loading rates (g/m^2/year)
- Actual pollution load in population equivalents (pe), assuming 44 g BOD/pe/day and 10 g TN/pe/day (Aquafin 2013). For the manure treatment wetlands the pe was calculated based on nitrogen content and assuming 10 g TN/pe/day.
- Hydraulic retention time (HRT: d)
- Hydraulic loading rate (HLR: m^3/m^2/d)
- Denitrification potential, i.e. the amount of nitrogen that can be denitrified, was defined as the amount of kjeldahl nitrogen removed in the system plus nitrite and nitrate present in the influent (mg N/L). The denitrification efficiency was calculated based on the remaining effluent nitrite and nitrate concentrations relative to the denitrification potential (%).
  - E.g. Denitrification potential at the Deurle installation:
    The average influent KjN concentration was 26.0 mg N/L and the sum of NO_3^- and NO_2^- was 1.2 mg N/L. In effluent there was still 21.8 mg KjN/L present. The denitrification potential is thus (26.0–21.8) mg N/L + 1.2 mg N/L = 5.4 mg/L
  - E.g. Denitrification efficiency at the Deurle installation:
    The average sum of nitrate and nitrate concentrations in the effluent was 0.43 mg N/L. The denitrification efficiency is thus (5.4–0.43) mg N/L / 5.4 mg N/L = 92 %

The data obtained this way were further analyzed by using Excel (Microsoft 2010). To analyze the treatment efficiency of each type of wetland, a histogram was produced using the influent and effluent concentrations for each type of wetland per component of interest (TN, TP). The dependence between the phosphorus removal efficiency and the age of the CW was studied by calculating the Pearson correlation factor (R^2) for the Aquafin operated wetlands, as an indicator of adsorption saturation.

14.3 Location, Number and Types of Constructed Wetlands

The database contains currently information on 406 constructed wetlands for wastewater treatment. More than half of these wetlands (56 %) are individual wastewater treatment systems for single families (Fig. 14.1, <10 %). Almost a fifth (18 %) of the wetlands is constructed to treat agricultural wastewater, and 14 % of the wetlands were built to treats wastewater from e.g. companies, schools and restaurants. Only 10 % of the wetlands are operated by Aquafin N.V, but they correspond to approximately 40 % of the total I.E. that is treated in constructed wetlands according to our database. The "Innova Manure" wetlands also discussed in this chapter constitute approximately 12 % of the total I.E. that is treated in constructed wetlands. The location of the Aquafin operated wetlands and the "Innova Manure" wetlands discussed in this chapter are illustrated on the maps in Figs. 14.2 and 14.3.

Currently, the most popular type of wetland is the vertical flow type (VF; Fig. 14.4). Their numbers have increased tremendously since 2004 when the previous overview on Flemish wetlands was published (Rousseau et al. 2004). In 2004, there were only 34 VF CWs in the database, now we found references to 287 VF CWs. The change is mainly caused by the popularity of VF CWs among the individual treatment systems which have been built in recent years to meet the discharge regulations set up by EU (1991[b]). Free water surface flow (FWS) CWs are more popular than the horizontal sub-surface flow (HSSF) CWs. The HSSF CWs are not used

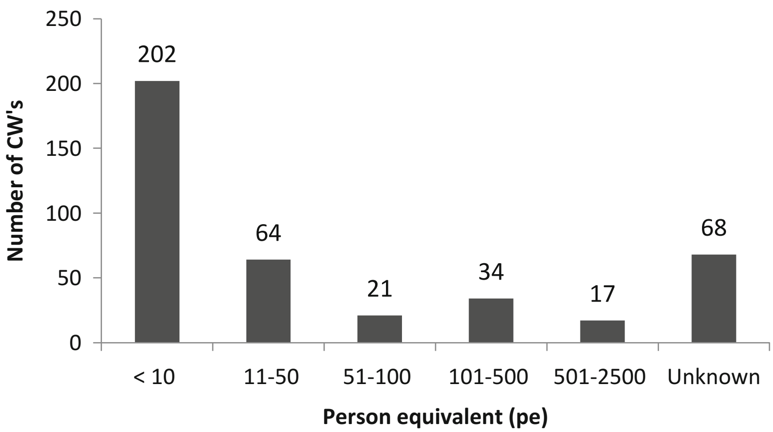

Fig. 14.1 Number of constructed wetlands in Flanders based on design person equivalent (pe)

Fig. 14.2 Location of constructed wetlands owned by Aquafin N.V. (=FWS; =VF; =HSSF; =VF-HSSF (combined); =SAF-SSF (tertiary); =RBC-SSF (tertiary)) (The interactive version of this map is available at: www.enbichem.ugent.be/FlandersWetlands ©GoogleMaps)

Fig. 14.3 Location of the "Innova Manure" wetlands (The interactive version of this map is available at: www.enbichem.ugent.be/FlandersWetlands ©GoogleMaps)

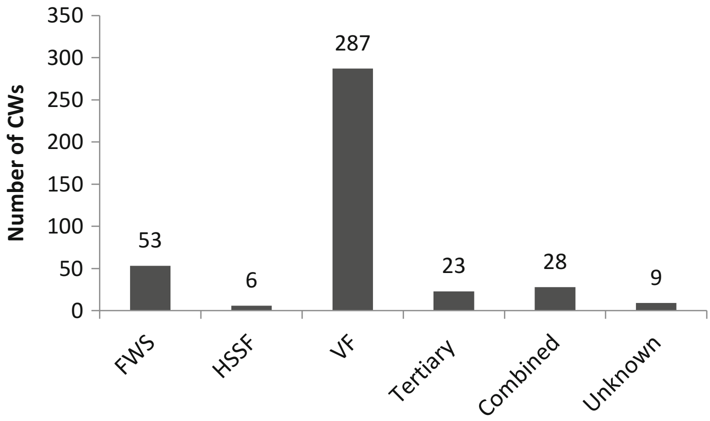

Fig. 14.4 Number of constructed wetlands in Flanders based on the wetland type

often as single stage wetlands but more often built as a tertiary treatment system after a rotating biological contactor or submerged aerated filter (Tertiary) or used in combination with vertical flow CWs (Combined). The number of unknown wetlands is caused by the incompleteness of some of the data acquired from newspaper articles and internet sites of the wetland contractors.

14.4 Removal of Nutrients from Municipal Wastewater

14.4.1 Free Water Surface Wetlands (FWS)

Only two of the free water surface wetlands are regularly and extensively monitored. Both are treating pre-settled municipal wastewater. In Deurle, the wastewater flows through 9 FWS CWs built in series, and in Latem through 13 FWS CWs. The design and operational characteristics of these installations can be found in Table 14.1.

It can be noticed that the actual loading in terms of inhabitant equivalent values based on BOD_5 and TN vary significantly. This can be due to the degradation of BOD_5 in the sewers and septic tanks. Septic tanks are still widely used at especially older households and it is thus possible that the organic matter degradation occurring in these tanks affects the influent composition at the WWTP. Nitrogen concentrations are not affected by presence of the septic tanks because no nitrification (and subsequent denitrification) occurs in these tanks. Some of the preliminary BOD_5 degradation is already taken into account in defining the inhabitant equivalents as 44 g BOD_5/pe/d instead of 54 g BOD_5/pe/d (Aquafin 2013), but it appears to be inadequate in the context of Flemish wastewaters. Furthermore, calculation of *pe* based on 12 g TN/pe/d has been shown to be more suitable for municipal wastewater in Flanders (Coppens et al. 2013).

Table 14.1 Design and operational characteristics of the FWS CWs

CW	Year of construction	Design capacity (pe)	BOD_5 loading (pe)[a]	TN loading (pe)[b]	Surface area (m^2)	Design footprint (m^2/pe)	Hydraulic loading rate (m^3/m^2/d)
Deurle	1989	900	314	938	3060	3.4	0.11
Latem	1989	720	260	815	3000	4.2	0.13

[a]Based on 44 g BOD_5/pe/d (Aquafin 2013)
[b]Based on 10 g TN/pe/d (Aquafin 2013)

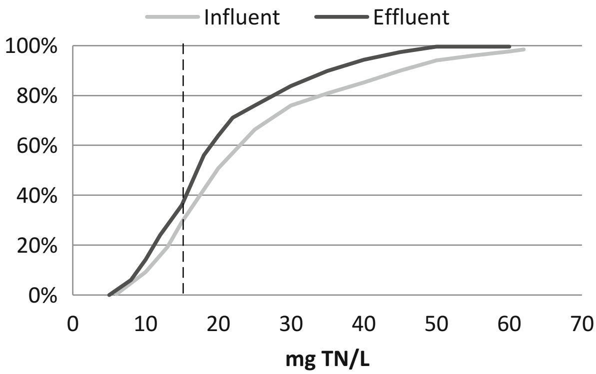

Fig. 14.5 The histogram for total nitrogen in the FWSs ($n_{infl}=250$; $n_{effl}=266$). The dashed line indicates the limit values set for effluent in the Flemish legislation VLAREM for installations >2000 pe

14.4.1.1 Nitrogen

The average TN concentrations in the influent are 21 ± 12 and 27 ± 14 mg TN/L for Latem and Deurle installations, respectively. The influent is thus quite diluted which is likely to be caused by the wide use of combined sewer systems. The influent total nitrogen content consists mainly of ammonium nitrogen (73 %), the remainder being organic nitrogen.

From Fig. 14.5 it can be seen that TN removal in the FWS CWs is very poor. As mentioned in the introduction, there are no nutrient limitations for wastewater treatment plants smaller than 2000 pe in Flanders. When the data on total nitrogen are compared to the Flemish standard for larger installations (15 mg TN/L) it can be seen that only 36 % of the effluent samples would comply. Actually, the poor nitrogen removal in the two FWS wetlands is also emphasized, as 29 % of the influent samples already achieve the standard limit value.

It is clear that the nitrification efficiency is very low in these systems (Fig. 14.6). A reduction in NH_4^+ of only 1 ± 2 mg N/L is achieved in these systems. The low nitrification efficiency is likely due to high nitrogen loading. Indeed, the observed TN influent loading rates 600 ± 335 g TN/m^2/year and 837 ± 381 g TN/m^2/year for the Latem and the Deurle system, respectively, are high in comparison to values

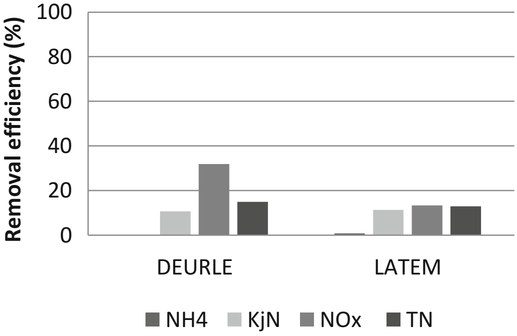

Fig. 14.6 Removal efficiency of nitrogen species in the FWSs

summarized in e.g. Vymazal (2007) of 466 g TN/m^2/year. In addition, the design flow rate (based on 150 L/pe/d), was met only in 35 % of the sampling events at the FWS installations. These high flow rates decrease the HRT, and this has been shown to affect nitrification efficiency (Toet et al. 2005).

It is logical to assume that the low nitrification efficiency also limited denitrification through low production of nitrite and nitrate. Denitrification potential was estimated by taking into account the ammonia oxidation that occurred in the system, producing nitrite and nitrate. The denitrification potential was very low, only 4.55 ± 1.13 mg N/L, and 92 % of the nitrate and nitrite present was removed in the FWS CWs.

14.4.1.2 Phosphorus

The removal of total phosphorus is very low in the concerned FWS CWs: average removal efficiencies were 5 % and 7 % for the Latem and Deurle installations, respectively. According to Fig. 14.7, only 40 % of the samples were under the Flemish standard (2 mg TP/L) for larger installations. However, this is a typical phenomenon in FWS wetlands where adsorption on the matrix is not possible. The phosphorus taken up by the plant will be released upon biodegradation of the plant biomass. Wallace and Knight (2006) stated that phosphorus removal in a FWS wetland is a result of accretion to sediments on the bottom of the wetland.

14.4.2 Vertical Flow Systems (VF)

Three of the VF systems in our database are regularly sampled. These VF CWs are used to treat pre-settled municipal wastewater. The Zemst-Larebeek and Sint-Niklaas Heimolen installations are composed of two parallel VF CWs. The Rillaar installation is the largest CW in Flanders, and it consists of four VF CWs operating in parallel. The design and operational characteristics of these installations can be found in Table 14.2. From this table, the high surface loading rate at the

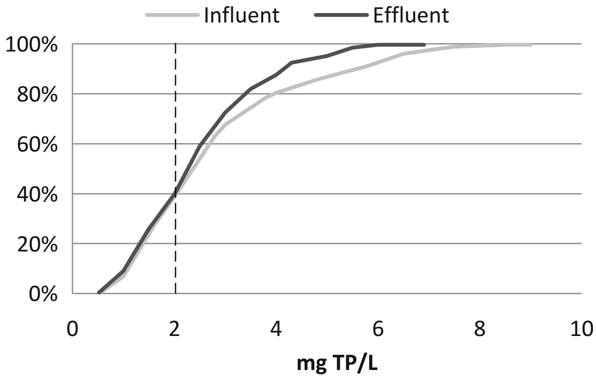

Fig. 14.7 The histogram for total phosphorus in the FWS wetlands ($n_{infl}=250$; $n_{effl}=266$). The dashed line indicates the limit values set for effluent in the Flemish legislation VLAREM for installations >2000 pe

Table 14.2 Design and operational characteristics of the VF CWs

CW	Year of construction	Design capacity (pe)	Actual BOD_5 capacity (pe)[a]	Actual TN capacity (pe)[b]	Surface area (m^2)	Design footprint (m^2/pe)	Hydraulic loading rate (m^3/m^2/d)
Zemst-Larebeek	2000	423	463	1880	940	2.2	0.57
Rillaar	2009	1800	1170	1880	12,000	6.7	0.02
Sint-Niklaas Heimolen	2000	243	209	408	540	2.2	0.13

[a]Based on 44 g BOD_5/pe/d (Aquafin 2013)
[b]Based on 10 g TN/pe/d (Aquafin 2013)

Zemst-Larebeek installation jumps out. This is probably due to the combined sewers and the exceptionally high proportion of surface and/or infiltrated groundwater in the influent stream.

14.4.2.1 Nitrogen

The three VF CWs in the database, Zemst-Larebeek, Rillaar and Sint-Niklaas Heimolen CWs, receive influent which contains on average 35 ± 34 mg TN/L, 66 ± 25 mg TN/L and 58 ± 25 mg TN/L for, respectively. The TN at the Rillaar and Sint-Niklaas Heimolen installations consists mainly of NH_4^+ nitrogen (78 %). At the Zemst-Larebeek installation the proportion of NH_4^+-N is slightly lower (58 %) due to the presence of nitrite and especially nitrate in the influent (5.2 ± 4.4 mg N/L; 13 %), which are most likely designated to agricultural runoff.

Compared to the FWS CWs, the VF CWs achieve a better total nitrogen removal. However, only 23 % of the effluent samples would meet the Flemish standard 15 mg TN/L set for larger installations, while almost 8 % of influent samples are already under this limit (Fig. 14.8).

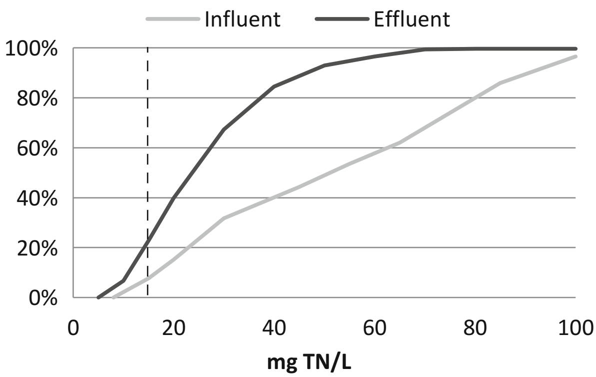

Fig. 14.8 The histogram for total nitrogen in the VFs (n = 284). The dashed line indicates the limit value set for effluent in the Flemish legislation VLAREM for installations >2000 pe

Fig. 14.9 Removal efficiency of nitrogen species in the VFs

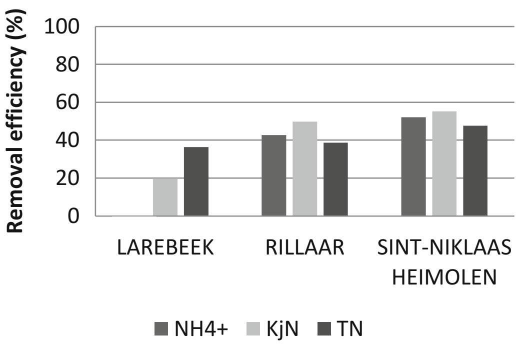

Figure 14.9 gives an overview of the average removal efficiency of nitrogen species in the three VF CWs. In general, kjeldahl nitrogen is rather efficiently removed by ammonification and nitrification. It seems though, that nitrification is poor at the Zemst-Larebeek installation because the average concentration of ammonium nitrogen increases by approximately 20 % during the treatment. It is likely that the hydraulic conditions at the Zemst-Larebeek installation could explain the poor ammonium removal. The biological processes could be hindered because of the high hydraulic loading rate (Table 14.2). The actual HLR (0.57 m/d) is approximately 5 times higher than the design HLR (0.12 m/d) and the design HLR was met at 22 % of the sampling events. The influent TN loading rate at the Zemst-Larebeek installation is thus much higher than at the other two VF CWs (Rillaar: 475 ± 183 g TN/m^2/year; Sint-Niklaas Heimolen: 1970 ± 1230 g TN/m^2/year). The influent loading rate at the Zemst-Larebeek installation was on average 5060 ± 8630 g TN/m^2/year, which is also remarkably higher than usually reported for VF CWs, 1222 g/m^2/year Vymazal (2007).

Denitrification was rather efficient in the VF CWs. Usually, denitrification is limited for single stage VF constructed wetlands because of the lack of anoxic zones (Vymazal 2007). The denitrification potential was calculated to be 35 mg N/L in the

Rillaar and Sint-Niklaas Heimolen CWs and slightly lower, 21.8 mg N/L, in the Zemst-Larebeek CW. On average, an 85 % denitrification efficiency was obtained in the VF CWs. The concentration of nitrification products, nitrate and nitrite, was found to increase in the effluent of Rillaar (5.9 ± 3.1 mg N/L) and Sint-Niklaas Heimolen (4.3 ± 4.3 mg N/L), but these values are low in comparison with literature (24.4 mg N/L; Vymazal 2007).

14.4.2.2 Phosphorus

Phosphorus removal in the VF wetlands is in general more efficient than in the FWS wetlands, due to the presence of a matrix. However, the matrix, e.g. gravel, has usually a low sorption capacity which also decreases over time due to saturation (Xu et al. 2006). Furthermore, the phosphorus removal in VF CWs can also be restricted due to changing redox conditions (Vymazal 2007).

The average removal efficiency of TP varies greatly between the VF CWs: 50 ± 30 %, 29 ± 49 % and 2.4 ± 108 % for the Rillaar, Sint-Niklaas Heimolen and Zemst-Larebeek installations, respectively. Only 25.3 % of the effluent samples reach the Flemish standard for large installations, 2 mg TP/L (Fig. 14.10). Pearson correlation analysis was further used to investigate whether the phosphorus removal efficiency is dependent on the age of the CW, i.e. the saturation state of the matrix. It appeared that there was no correlation between these two parameters ($R^2 \approx 0$; data not shown).

14.4.3 Horizontal Sub-Surface Flow Systems (HSSF)

Three HSSF CWs were studied based on the data on removal efficiencies and flow rates collected from the online database. Two of these systems are currently in operation. The Kiewit CW, consisting of 9 parallel wetlands, was shut down in spring 2014 after 15 years of operation. The Dikkelvenne CW is operated with 4 parallel

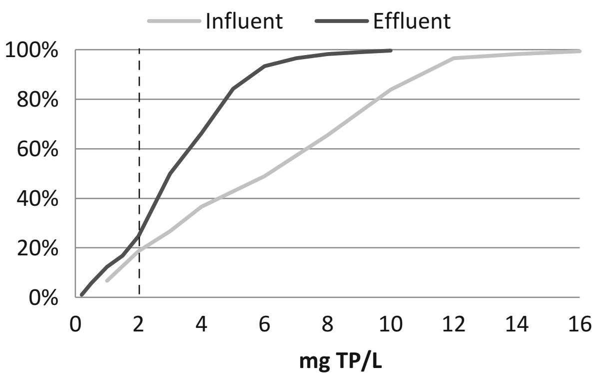

Fig. 14.10 The histogram for total phosphorus in the VF wetlands (n = 395). The dashed line indicates the limit value set for effluent in the Flemish legislation VLAREM for installations >2000 pe

Table 14.3 Design and operational characteristics of the HSSF CWs

CW	Year of construction	Design capacity (pe)	BOD_5 loading (pe)[a]	TN loading (pe)[b]	Surface area (m^2)	Design footprint (m^2/pe)	Hydraulic loading rate (m^3/m^2/d)
Dikkelvenne	2007	900	787	1320	1800[c]	2.0	0.21
Hasselt-Kiewit	1999	137	84	131	640	4.7	0.04
Zemst-Kesterbeek	2001	315	279	586	1300	4.1	0.07

[a]Based on 44 g BOD_5/pe/d (Aquafin 2013)
[b]Based on 10 g TN/pe/d (Aquafin 2013)
[c]Based on an aerial photo

HSSF CWs and the Zemst-Kesterbeek CW has 2 parallel HSSF CWs. The design and operational characteristics of these installations can be found in Table 14.3.

Similarly as in the case of the FWS and VF CWs, the nitrogen loading can be seen as the dominant parameter in determining the actual loading in the HSSF CWs. What also can be noticed is the smaller design footprint of the Dikkelvenne installation in comparison to the two older systems.

14.4.3.1 Nitrogen

The total nitrogen concentrations in the influent were 33.8 ± 14.9 mg N/L, 54.4 ± 20.6 mg N/L and 61.7 ± 28.5 mg N/L for the Dikkelvenne, Hasselt-Kiewit and Zemst-Kesterbeek installations, respectively. The TN at the Hasselt-Kiewit and Zemst-Kesterbeek installations consisted mainly of NH_4^+-N (80 %) and organic nitrogen, but the Dikkelvenne installation received also some nitrite and nitrate (NH_4^+-N: 61 % NO_x-N:8 %).

Based on the histogram for total nitrogen, the HSSF CWs achieve similar efficiency as the VF CWs. 28 % of the effluent samples of the HSSF CWs were under 15 mg N/L, as required for large wastewater treatment installations in Flanders (Fig. 14.11).

When the removal efficiency of the different nitrogen species is observed in more detail, one can notice that, overall, the performance of the HSSF CWs is similar to that of the VF CWs (Fig. 14.12) the nitrification efficiency seems limited. In case of single stage HSSF CWs, the low nitrification efficiency can, at least partly, be explained by limited oxygen transfer which is typical in these wetlands (Tyroller et al. 2010; Vymazal 2007). Furthermore, it is likely that the high influent loading rate of the two systems (Dikkelvenne: 2430 ± 1390 g TN/m^2/year; Zemst-Kesterbeek: 1160 ± 1080 g TN/m^2/year) and the lowered HRT, which is linked to the application of combined sewers, decrease their overall nitrogen removal efficiency. The total nitrogen loading rate reported in literature, 945 g/m^2/year (Vymazal 2009) and 644 g/m^2/year (Vymazal 2007), is lower than the values found here. The treatment performance at the Hasselt-Kiewit installation was even lower in comparison to the two

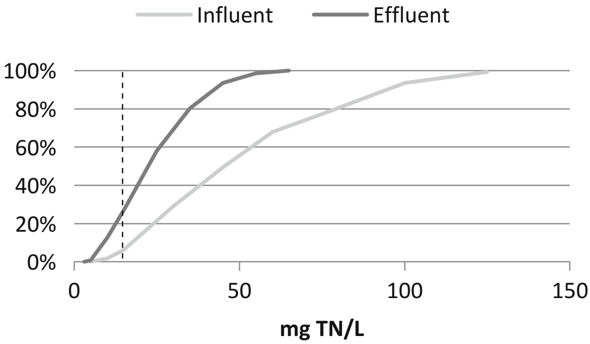

Fig. 14.11 The histogram for total nitrogen in the HSSFs ($n_{infl} = 283$; $n_{effl} = 284$). The dashed line indicates the limit value set for effluent in the Flemish legislation VLAREM for installations >2000 pe

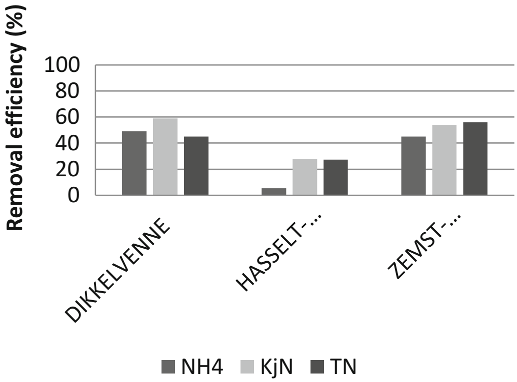

Fig. 14.12 Average removal efficiencies of nitrogen species in the HSSF wetlands

other installations. This can have been caused by age related clogging of the wetland matrix but it could not be verified.

Denitrification seems to be more efficient in the HSSF CWs than in the VF CWs as expected. Firstly, a lower concentration of nitrite and nitrate could be found in the effluent of the HSSF CWs (2.2 ± 1.7 mg N/L) in comparison to the VF CWs (4.5 ± 3.7 mg N/L). Secondly, the HSSF CWs were able to achieve denitrification efficiency of 97 %, the average denitrification potential being 32 ± 8.7 mg N/L, in comparison to 85 % in the VF CWs.

14.4.3.2 Phosphorus

As is usual for constructed wetlands, the phosphorus removal in the studied HSSF CWs was also rather low. The Zemst-Kesterbeek installation achieved the best average removal (44 %) in comparison to the other two HSSF CWs (Dikkelvenne: 29 % and Hasselt-Kiewit: 7 %). Thus, only 23.2 % of the effluent samples reached the Flemish discharge standard of 2 mg TP/L for large installations (Fig. 14.13). No correlation between the TP removal efficiency and age of the system was found ($R^2 \approx 0$).

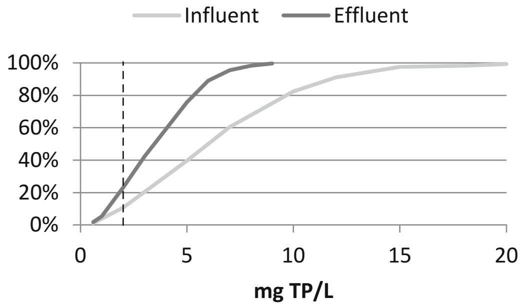

Fig. 14.13 The histogram for total phosphorus in the HSSFs ($n_{infl} = 283$; $n_{effl} = 285$). The dashed line indicates the limit value set for effluent in the Flemish legislation VLAREM for installations >2000 pe

Table 14.4 Design and operational characteristics of the VF-HSSF CWs

CW	Year of construction	Design capacity (pe)	BOD_5 loading (pe)[a]	TN loading (pe)[b]	Surface area (m^2)	Design footprint (m^2/pe)	Hydraulic loading rate ($m^3/m^2/d$)
Bierbeek-Kleinbeek	2000	189	162	276	660	3.5	0.21
De Pinte	2000	675	390	1140	2250	3.3	0.10
Ieper-Hollebeek	2000	360	690	1060	1080	3.0	0.27
Mol-Postel	1998	270	826	327	1440[c]	5.3	0.03
Pervijze	2000	630	406	1176	2212	3.5	0.14

[a]Based on 44 g BOD_5/pe/d (Aquafin 2013)
[b]Based on 10 g TN/pe/d (Aquafin 2013)
[c]Based on an aerial photo

14.4.4 Combined Wetlands: VF-HSSF

Combined systems, which combine two or more wetlands in series, have the advantage over single stage CWs that they are usually better at total nitrogen removal (Vymazal 2007). This is due to the existence of both oxic and anoxic zones. In the five combined wetlands discussed here pre-settled wastewater is first treated in a vertical subsurface flow CW after which the secondary effluent is sent to a horizontal subsurface flow CW. The design and operational characteristics of these installations can be found in Table 14.4.

The same trend, with a few exceptions, is noticeable as with previous CW configurations, i.e. that the TN load is high in comparison to the BOD_5 one in terms of I.E. In case of the Mol-Postel treatment plant, the BOD_5 loading exceeds that of the TN when measured in I.E. This is due to the special influent composition caused by a nearby cheese factory. At the Ieper-Hollebeek installation, the influent is highly loaded in both organic matter and nitrogen. The specific reason for this is unknown.

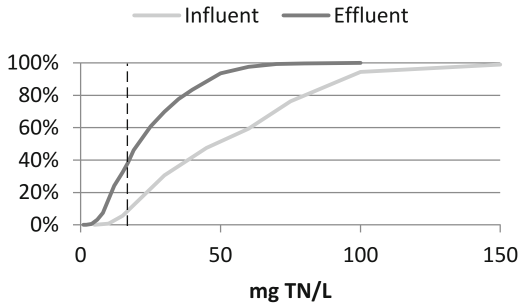

Fig. 14.14 The histogram for TN in the VF-HSSF wetlands ($n_{infl}=562$; $n_{effl}=602$). The dashed line indicates the limit value set for effluent in the Flemish legislation VLAREM for installations >2000 pe

14.4.4.1 Nitrogen

The total nitrogen content of the influent wastewater differed quite remarkably between the different VF-HSSF installations. The average total nitrogen concentration was 53.9 ± 69.9 mg N/L of which on average 66 % consisted of ammonium nitrogen. The lowest TN concentration was observed in the influent of Ieper-Hollebeek (35.6 ± 23.1 mg N/L) which was the only one to receive some nitrite and nitrate in the influent (11 %). The highest TN concentration was recorded at Mol-Postel (84.0 ± 26.9 mg N/L) where a large proportion of organic nitrogen (52 %) in addition to ammonium nitrogen (48 %) was registered. The reason for the high organic nitrogen at Mol-Postel load is a nearby located cheese factory.

As is theoretically expected, the removal of total nitrogen is better in combined systems than single stage wetlands (VF and HSSF). The combined systems achieved a cumulative removal efficiency of 33 % (Fig. 14.14), when considering effluent samples containing maximum 15 mg TN/L. In comparison, the cumulative removal efficiencies of TN were 23 % and 28 % for the VF and HSSF CWs, respectively.

When the nitrogen removal is observed in more detail, clear differences between the installations can be noticed (Fig. 14.15). Especially the NH_4^+ removal efficiency in the Ieper-Hollebeek and Mol-Postel installations appears to be low in comparison to the others. The characteristics of the influent at Ieper-Hollebeek and Mol-Postel are likely to cause these differences. Firstly, the influent total nitrogen loading rate at the Ieper-Hollebeek installation (2410 ± 2024 g TN/m^2/year) is higher than the loading rates of the other installations (1260 ± 838 g TN/m^2/year) and also higher than the values reported in literature for VF CWs (1220 g N/m^2/year; Vymazal 2007). Secondly, it appears that the NH_4^+-nitrogen removal efficiency is comparable to the organic loading of the combined CWs. In short, when the BOD_5 loading is high, the NH_4^+ removal decreases. It is thus probable that the oxygen consumption of the organic matter degradation restricts the growth and activity of nitrifying organisms.

The concentration of nitrification products, nitrite and nitrate increases in the effluent of most of the combined wetlands (not in Ieper-Hollebeek). The lowest concentrations of nitrite and nitrate are found in the effluent at Mol-Postel, which is the CW receiving the highest organic load. It appeared also that the Mol-Postel CW is the most efficient one at denitrification. It achieved 96 % denitrification efficiency

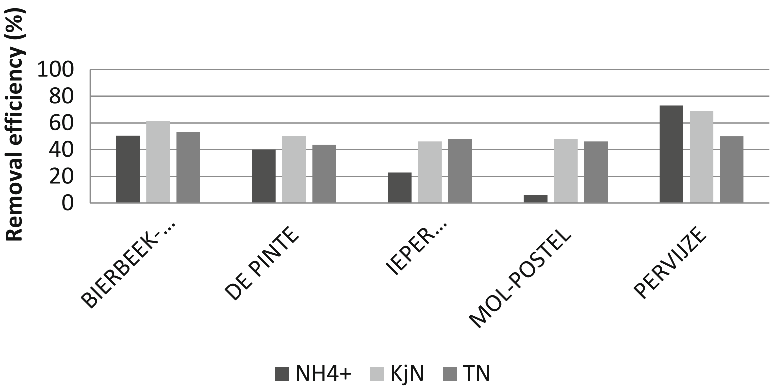

Fig. 14.15 The average removal efficiency of nitrogen species in VF-HSSF CWs

(denitrification potential 43.2 mg N/L) whereas the performance of the other combined wetlands was comparable to the single stage CWs (85 %; 30.5 ± 8.7 mg N/L).

14.4.4.2 Phosphorus

The phosphorus removal efficiency in the combined CWs varied between 23 % and 30 %. Because of the poor P removal, only 22 % of the effluent samples achieved the discharge limit of large installations, 2 mg TP/L (Fig. 14.16). The P removal efficiency did not decrease with the age of the combined systems (data not shown).

14.4.5 Tertiary Treatment Wetlands: RBC-HSSF and SAF-HSSF

There are 22 CWs in Flanders which are used as tertiary treatment for domestic wastewater, and of which sufficient data are available. 17 of these are treating effluent from a rotating biological contactor (RBC) and 5 of these are placed after a submerged aerated filter (SAF). The purpose of the CWs is to function as a post-treatment for the secondary effluent but also to act as a buffer system in case of high flow, e.g. due to a heavy rain fall. More specifically, the CW receives untreated influent if the flow rate exceeds 6 times the design flow rate Q_{14} (Q_{14} = 1,7*dry weather flow) and pre-settled influent if the flow rate is lower than this but higher than 3 times the Q_{14}. At most treatment sites there are one or two CWs after the secondary treatment. The largest installations are in some cases divided in three or four CWs. Further design and operational characteristics of the tertiary CWs are compiled in Table 14.5.

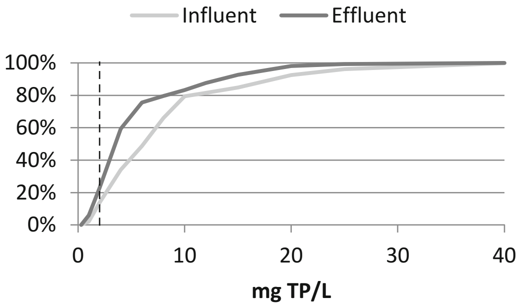

Fig. 14.16 The histogram for TP in the VF-HSSF wetlands ($n_{infl}=562$; $n_{effl}=600$). The dashed line indicates the limit value set for effluent in the Flemish legislation VLAREM for installations >2000 pe

Table 14.5 Design and operational characteristics of the tertiary CWs

	CW	Year of construction	Design capacity (pe)	BOD_5 loading (pe)[a]	TN loading (pe)[b]	Surface area (m^2)	Design footprint (m^2/pe)	Hydraulic loading rate (m^3/m^2/d)
RBC-HSSF-CW	Aalbeke	1996	450	326	596	500	1.1	0.30
	Asse-Bekkerzeel	2010	360	237	483	820[c]	2.3	0.10
	Avekapelle	2012	330	266	323	N/A	N/A	N/A
	Beauvoorde	2012	360	929	1010	840[c]	2.3	0.37
	Duffel	2011	800	318	654	1130[c]	1.4	0.10
	Gistel	2012	500	606	1010	N/A	N/A	N/A
	Lebbeke-Rooien	2012	113	62.8	136	240[c]	2.1	0.09
	Lokeren-Daknam	2013	500	619	1280	1170[c]	2.3	0.39
	Lovie	2012	540	276	600	900[c]	1.7	0.16
	Moerbeke	2006	405	326	580	760[c]	1.9	0.12
	Ninove-Rendestede	2012	153	51.6	86.0	180[c]	1.2	0.06
	Schorisse	2010	360	397	658	N/A	N/A	N/A
	St.Margriete	2014	450	208	530	N/A	N/A	N/A
	St.Maria Lierde	2000	850	1860	2960	425	0.56	1.7
	Stavele	2012	378	327	457	360	0.95	0.21
	Steenkerke	2013	270	48.8	119	N/A	N/A	N/A
	Vlissegem	2013	500	530	646	N/A	N/A	N/A
SAF-HSSF-CW	Loker	2007	675	480	657	1360[c]	2.0	0.07
	Wachtebeke-Overslag	2012	405	245	523	850[c]	2.1	0.09
	Watervliet	2009	810	456	1050	1570[c]	1.9	0.24
	Wervik Kruiseke	2011	729	371	575	N/A	N/A	N/A
	Wingene St.Pietersveld	2007	540	712	807	N/A	N/A	N/A

[a]Based on 44 g BOD_5/pe/d (Aquafin 2013, [b]Based on 10 g TN/pe/d (Aquafin 2013), [c]based on an aerial photo
N/A not available

It can be concluded from Table 14.5 that the influent total nitrogen loading is often higher than the design capacity, similarly to other installations. At RBC-HSSF CW sites Gistel, Lokeren-Daknam and Schorisse the design capacity is exceeded by at least 100 %. The organic loading at the Beauvoorde and St. Maria Lierde installations is additionally very high. The St. Maria Lierde installation receives in addition to municipal wastewater also runoff from agricultural land (Lesage 2006), which is likely to increase the loading. The total nitrogen loading at the SAF-HSSF CW Watervliet is also higher than expected based on its design capacity. The results reported here are based on the performance of the complete installation, i.e. secondary and tertiary treatment together.

14.4.5.1 Nitrogen

The influent nitrogen content at the tertiary treatment plants is comparable to the other installations. The TN concentrations in the influent were 51.3 ± 23.9 mg N/L and 52.9 ± 18.5 mg N/L for the RBC and SAF-HSSF CWs, respectively. The fraction of ammonium nitrogen was on average 74 %. Only the NH_4^+-N proportion at the Beauvoorde and St. Maria Lierde installations differed from the others being 42 % and 52 %, respectively. It is possible that the runoff from fields, that was stated to occur at the St. Maria Lierde installation, contains soil, plant debris and manure which increase the organic nitrogen content of the influent.

Based on the cumulative removal efficiency of total nitrogen, the SAF-HSSF CWs are more efficient in TN removal than the RBC-HSSF CWs. 59 % of the effluent samples discharged from a SAF-HSSF CW comply with the Flemish standard of 15 mg TN/L, in comparison to 44 % of the effluent samples originating from a RBC-HSSF CWs (Fig. 14.17).

Nitrification is mainly the task of the secondary treatment (RBC or SAF) at these installations. The ammonium and kjeldahl nitrogen removal efficiency in these treatment systems was remarkably better and less variable than in the other installations. The RBC and SAF-HSSF CWs could achieve a removal of 90 % and higher for ammonium and kjeldahl nitrogen (Figs. 14.18, and 14.19) whereas other installations reached barely 40 %.

Denitrification occurs mainly in the tertiary treatment HSSF wetland. The denitrification potential was calculated to be 48.3 ± 15.0 mg N/L for the RBC-HSSF CWs and 52.2 ± 17.7 mg N/L for the SAF-HSSF CWs. Hence, the denitrification potential is higher in the tertiary treatment systems than in the other installations. The denitrification efficiency is better in the SAF-HSSF CWs (78 %) than in the RBC-HSSF CWs (67 %). In comparison to other installations, the tertiary treatment systems achieve lower denitrification efficiency. Because of this, the nitrite and nitrate concentrations are high in the effluent of the tertiary treatment systems (14.5 ± 6.0 mg N/L).

The problem with denitrification in tertiary treatment systems is that a large portion of the bioavailable organic matter is already degraded in the secondary treatment, limiting the denitrification in the tertiary treatment. To analyze the organic

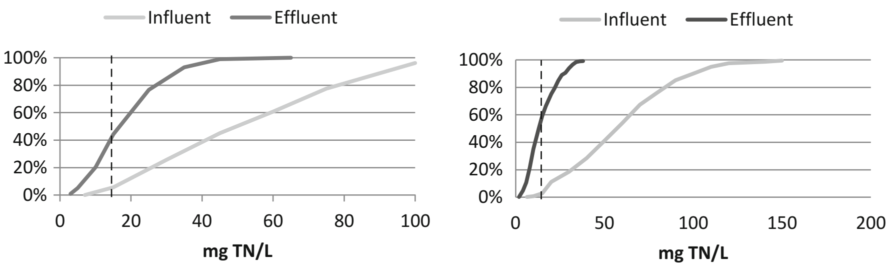

Fig. 14.17 The histogram for TN in the RBC-HSSF wetlands ($n_{infl}=970$; $n_{effl}=977$, *left*) and the SAF-HSSF wetlands ($n_{infl}=383$; $n_{effl}=384$, *right*). The dashed line indicates the limit value set for effluent in the Flemish legislation VLAREM for installations >2000 pe

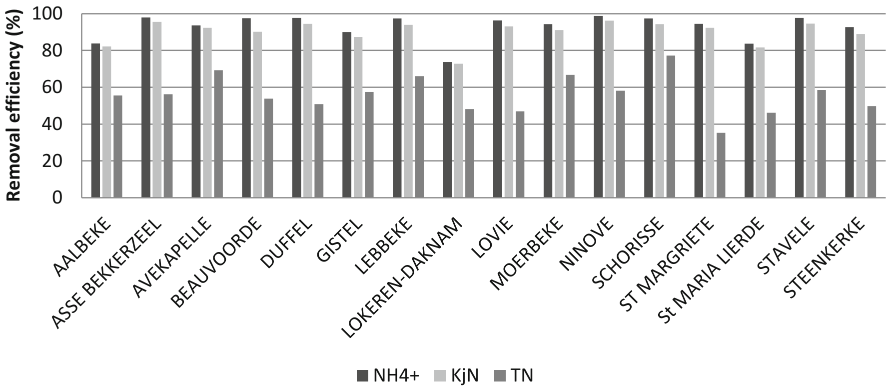

Fig. 14.18 Average removal efficiencies of nitrogen species in the RBC-HSSF CWs

loading received by the CWs, it was calculated based on the available flow rates how often the HSSF CWs receive (pre-settled) influent. Influent was sent directly to the RBC-HSSF CWs on 3 % of the operation days and additionally, pre-settled influent on 5 % of the operation days. In case of SAF-HSSF CWs the values were somewhat lower, 1 % and 3 %, respectively. However, as denitrification was more efficient in the SAF-HSSF CWs, the organic loading in the HSSF CWs is presumably not the main limiting factor.

14.4.5.2 Phosphorus

The phosphorus removal efficiency is similar in both types of tertiary systems. 30 % of the effluent samples from the RBC-HSSF CWs and 11 % of the effluent samples from the SAF-HSSF CWs were under the discharge limit for large installations, 2 mg TP/L (Figs. 14.19, and 14.20). In RBC-HSSF CWs the TP removal varies between 31 % and 52 %, with two exceptions of 18 % and 19 %. In SAF-HSSF CWs the TP removal efficiency is generally between 29 % and 49 %, but in one system

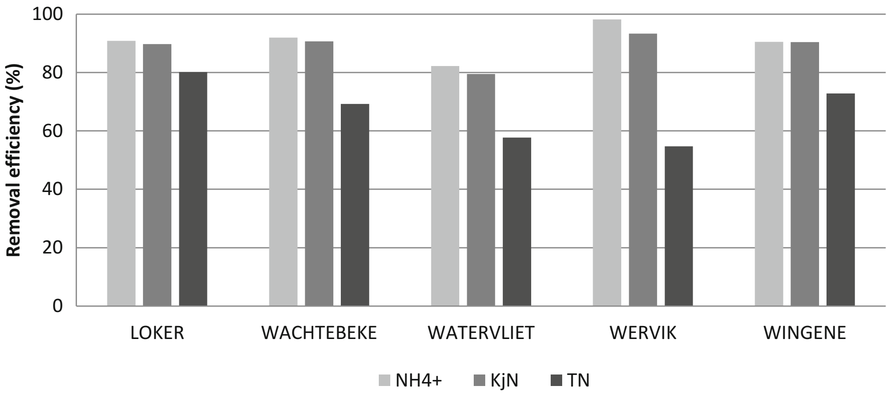

Fig. 14.19 Average removal efficiencies of nitrogen species in the SAF-HSSF CWs

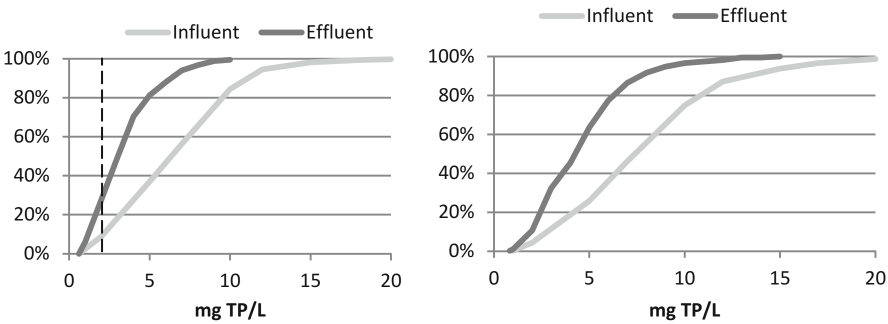

Fig. 14.20 The histogram for TP in the RBC-HSSF wetlands ($n_{infl}=968$; $n_{effl}=976$, *left*) and in the SAF-HSSF wetlands ($n_{infl}=383$; $n_{effl}=384$, *right*). The dashed line indicates the limit value set for effluent in the Flemish legislation VLAREM for installations >2000 pe

slightly lower, 21 %. These values are similar to other installation types. The removal efficiency was not noticed to decrease with the age of the system (data not shown).

14.5 Agricultural Wastewater N and P Removal

The installations for treating pig manure consist of a multi-bed system, with VF and HSSF CWs as well as open ponds. Most of the systems are situated in the province West-Flanders, which is characterized by a very high density of animal husbandry and in particular a very intensive pig farming industry. The systems vary in size between 0.35 and 1.5 ha and having a capacity of 5000–20,000 t/year of manure post-treatment. Based on COD and TN concentrations of ingoing influent, the loading is equivalent to 300–11,00 pe.

Table 14.6 Design and operational characteristics of the "Innova Manure" treatment wetlands

CW	Year of construction	Design capacity (pe)	TN loading (pe)[a]	Surface area (m^2)	Design footprint (m^2/pe)	Hydraulic loading rate ($m^3/m^2/d$)
Ichtegem	2006	288	288	3510	12	1.0
Gistel	2007	1159	1159	14,100	12	1.0
Langemark I	2008	356	392	4332	12	1.1
West-Vleteren	2009	1233	863	15,000	12	0.7
Pittem	2009	719	863	8750	12	1.2
Hoogstraten	2013	986	1233	12,000	12	1.3
Langemark II	2015	360	N/A	4375	10	N/A

[a]Based on 10 g TN/pe/d
N/A not available

Based on the monthly monitoring, flows to and within the system are adapted to restrict the nutrient losses to the receiving surface water. When concentrations in the final buffer lagoon of the wetland exceed the discharge limits, the pumping schedule within the system is altered to provide for longer HRT within the system and to block all possible discharge until values return to below allowable levels. The loading of the manure treatment wetland systems is dimensioned in function of COD and TN. Table 14.6 presents the design and operational characteristics of the six treatment wetlands studied. The Langemark II CW system is only recently taken into operation and no sufficient data from it is yet available.

14.5.1 Nitrogen

The influent TN concentrations can vary greatly between 50 and 800 mg/L with an average value at around 300 mg/L (Fig. 14.21). The systems are well equipped to deal with fluctuating inlet concentrations and rarely any values over 15 mg/L are ever observed. In those cases when values above the discharge limit are observed, discharge is blocked and the effluent is recirculated back into the wetland.

14.5.2 Phosphorus

The manure treatment wetlands are designed in such a manner that phosphorous build-up within the system is avoided. The loading rate of the pre-treated manure is limited to removal capacity via plant uptake. The reed plants are annually harvested and exported off-site to assure any potential accumulation. TP concentrations of the pre-treated manure influent are < 15 mg/L and the wetlands have no problem to achieve the <2 mg/L threshold as can be observed in Fig. 14.21.

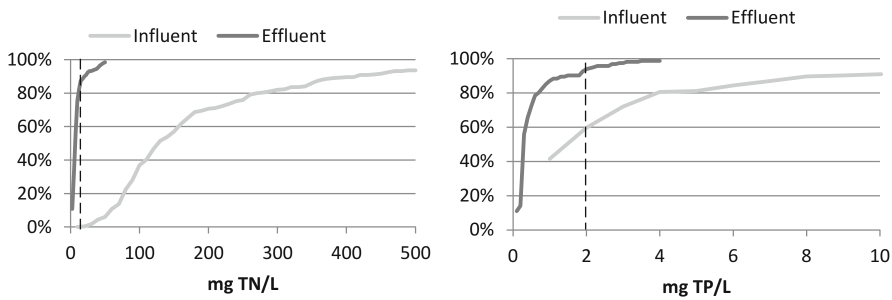

Fig. 14.21 The histogram for TN (*left*) and TP (*right*) in the manure treatment wetlands (n = 249). The dashed line indicates the limit value set for effluent in the Flemish legislation VLAREM for installations discharging processed manure into surface water (15 mg/l TN, 2 mg/l TP)

14.6 Comparison of the Performance of Constructed Wetlands

In this study, the treatment performance of 35 CWs treating municipal wastewater and of 6 manure treatment wetlands was studied in more detail. The wetlands treating municipal wastewater were located all around Flanders. Most of these wetlands are built after the year 2000, and their design capacities vary between 113 and 1800 pe. Free-water-surface CWs (2 wetlands), vertical flow (3 wetlands) and horizontal flow CWs (3 wetlands) are used as single stage CWs, and five cases are combined systems with VF CW followed by HSSF CW (VF-HSSF CWs). Twenty two wetlands are used for tertiary treatment after RBC (17) or SAF (5). The manure treatment wetlands studied are mainly located in the region of West-Flanders which is known for its intensive agriculture. Their design capacities vary between 300 and 1100 pe. All systems consist of a combination of multiple beds.

The influent composition at the different treatment plants was overall similar. The organic loading was in general lower than expected based on the design capacity (pe), but the total nitrogen load was often higher (Table 14.7). This was expected to be due to the biodegradation of BOD_5 in the sewer system and septic tanks. The TN concentrations were not observed to be higher than reported in literature earlier, but the high flow rate caused the increased TN loading. The high flow rate is caused by the combined sewers in which wastewater is diluted by surface water and infiltrating groundwater. These sewer systems are still widely used in Flanders. When the situation is compared to a large activated sludge treatment plant in Ghent (207,000 pe), a similar trend is observed. Accordingly, a study on Flemish nutrient streams states that the often applied 10 g TN/pe/d possibly underestimates the TN content in the domestic wastewater in Flanders and that 12 g TN/pe/d should be used instead (Coppens et al. 2013).

The nutrient emissions from the CWs were compared to the discharge standards of larger wastewater treatment plants (>2000 pe) because the Flemish legislation on the treatment performance of small-scale treatment systems, which includes all

Table 14.7 Average influent and effluent loading at the CWs

Wastewater	Type CW	Influent loading (g TN/m^2/year)	Effluent loading (g TN/m^2/year)	Reduction (%)	Influent loading (g TP/m^2/year)	Effluent loading (g TP/m^2/year)	Reduction (%)	References
Domestic	FWS	719	622	13	86	78	9.3	This study
		466	219	53	138	68	51	Vymazal (2007)
Domestic	VF	2500	1330	47	256	156	39	This study
		1220	592	52	126	54	57	Vymazal (2007)
Domestic	HSSF	1340	575	57	180	116	36	This study
		945	580	39	248	179	28	Vymazal (2009)
		644	394	39	141	96	32	Vymazal (2007)
		590[a]	360[a]	39	133[a]	84[a]	37	Vymazal (2002)
Domestic	VF-HSSF	1490	809	46	197	146	26	This study
Domestic	Tertiary	N/A	N/A		N/A	N/A		
Pre-treated pig manure	Combined	70,300	3790	95	1470	236	76	This study

[a]Average of reported values
N/A not applicable

CWs in Flanders, is not strict. Thus, there are no nutrient limitations for these small-scale treatment plants. This is rather contradictory taking into account the fact that the whole of Flanders is categorized as a nitrate sensitive area by the EU (EU 2014). Nutrient pollution from households and agriculture is a significant problem in Flanders causing elevated nutrient concentrations in surface and ground waters (EEB 2010; EU 2013). Brooks and small rivers, which are often the discharge waters of small-scale treatment plants, are thus at risk of eutrophication. Based on our calculations, approximately 70–80 % of the effluent samples do not meet the requirements set for TN emissions for large installations.

The FWS CWs appeared to show very low overall nitrogen transformation efficiency (Table 14.8). The influent consisted mainly of ammonium nitrogen but only a small fraction was nitrified. Therefore, the production of nitrite and nitrate was essentially not occurring, and was limiting denitrification. It was concluded that the problems related to the low nitrification efficiency are related to the low HRT and poor oxygen transfer in these systems. As a consequence, the TN removal efficiency was lower and the TN concentration higher than in reported in literature for other FWS CWs (Vymazal 2007).

The VF and HSSF CWs showed similar nitrogen removal efficiencies. Nitrification seemed to be the limiting process in both systems. It was surprising that the VF CWs also experienced problems related to oxygen transfer. This was again expected to be caused by the high nitrogen loading rate, which was observed in case of both types of wetlands. As expected, denitrification was slightly more efficient in case of HSSF CWs than VF CWs, which resulted in lower nitrate concentration in the HSSF CW effluent. The remaining TN and ammonium nitrogen concentrations or the TN removal efficiency were in the range reported earlier in literature reviews (Vymazal 2007, 2009).

The combined systems, VF-HSSF CWs, could not achieve remarkably improved performance when compared to the single stage systems, VF and HSSF CWs. It was concluded that the nitrification step was limiting because of high loading rate.

The removal efficiency of nitrogen species was observed to be best in the tertiary treatment systems. Also, the tertiary treatment systems achieved the best nitrification efficiency. The nitrogen in the effluent was mainly in the form of nitrate, unlike in the other systems where it was ammonium. The oxygen transfer in the tertiary treatment systems was thus improved in comparison to basically all CWs as secondary treatment which had poor nitrification efficiency due to nitrification efficiency. Aeration of the secondary treatment CWs could offer a solution to the poor oxygen transfer, and should be considered to obtain better nutrient removal efficiency in these systems.

The denitrification efficiency was found to be slightly poorer in the tertiary systems than in the other systems (not FWS). This was possibly partly due to the consumption of organic matter in the secondary treatment.

The removal of total phosphorus was also studied. The FWS CWs showed the lowest TP removal efficiency, which was attributed to the lack of matrix material in these wetlands and thus a lack of adsorption sites. The other single stage and combined systems achieved a removal of approximately 20 %. The best removal effi-

Table 14.8 Average treatment performance of the different types of CW systems

Waste-water	Type CW	Influent TN concentration (mg N/L)	Effluent TN concentration (mg N/L)	Effluent NH_4^+ concentration (mg N/L)	Effluent NO_3^- concentration (mg N/L)	TN removal efficiency (%)	NH_4^+-N removal efficiency (%)	Effluent TP concentration (mg N/L)	TP removal efficiency (%)	N
Domestic	FWS	23.8	19.7	16.1	0.275	14	0.35	2.50	6.3	2
Domestic	VF	49.8	26.7	19.2	4.36	41	24	4.19	19	3
Domestic	HSSF	50.0	24.2	20.5	2.12	43	33	3.65	27	3
Domestic	VF-HSSF	53.9	24.3	17.6	3.85	48	38	5.42	22	5
Domestic	Tertiary	51.7	17.8	1.68	14.2	58	93	3.75	38	22
Pre-treated pig manure	Combined	192	10.1	N/A	N/A	95	N/A	0.63	85	6

N/A not available

ciency was achieved in the tertiary systems. The concentration of TP in effluent is comparable to reported values (Vymazal 2007), but these values are, however, above the effluent standards applied for larger treatment plants (>2000 pe). When the percentage of removed TP load is observed, it appears that the CWs in this study perform comparably to those reported in the literature. At the moment the matrix material is not chosen material with the purpose of maximizing the P removal and therefore, it could be possible to improve the TP removal efficiency by opting for an improved matrix, e.g. through iron amendments (Van Oirschot 2010). The aging of the installations during the period 2005–2014 was not found to affect the TP removal efficiency.

In comparison to the CWs treating municipal wastewater, the manure treatment wetlands are very efficient at the removal of both total nitrogen and phosphorus. On average 95 % of the TN load and 76 % of the TP load was removed (Table 14.7). The effluent standards set for the manure treatment wetlands were thus also fulfilled (Table 14.8). The difference is caused by the different operation and design of the systems. The manure treatment CWs are dimensioned larger than the CWs treating municipal wastewater, and mostly they are even over-dimensioned. Furthermore, in these CWs recycling of effluent is applied if needed and P removal is improved by frequent plant harvesting. It must be noted however, that intensive sampling is necessary to define the need for recycling, and this is laborious and costly.

14.7 Conclusions

The number of constructed wetlands for wastewater treatment has increased tremendously since 2004 when the last overview on the Flemish CWs was published. Especially the vertical flow constructed wetlands are popular, and most of the recently built VF CWs are individual wastewater treatment systems of single families. CW technology has thus shown to be an important sustainable solution for wastewater treatment in rural areas. Correct design can also contribute to decreasing nutrient load to the environment. Due to the current high nitrate concentrations in Flemish groundwater and surface water, it is advisable to revise the effluent standards for wastewater effluent from small-scale treatment plants.

The CWs for municipal wastewater treatment studied in this chapter achieve the treatment performance set in legislation. Currently, this only involves the reduction of organic loading and nutrient discharge is not controlled. When we analyzed the data on N and TP discharge, it was clear that most of the systems could not contribute significantly to reducing the nutrient levels in wastewater. The reason for this was found to be the TN loading caused by high flow rates. Due to this it is likely that the oxygen transfer, and thus nitrification, is hampered in most systems, especially the single stage and combined systems. Active aeration should thus be considered as an option in future installations.

Treatment wetlands for processing pig manure down to dischargeable levels are particularly designed and operated in such a manner that effluent above effluent standards is recirculated back into the wetland system. For TP, accumulation within the system is avoided by dimensioning the loading rate to levels well below annual removal capacity by plant uptake (and harvest export off-site). As regarding TN, the systems are currently over-dimensioned to 12 m^2/pe. which explains why reducing effluent levels to below 15 mg/L rarely poses any problems. Even though over-dimensioned, overall costs of building, operations and follow-up amount to approximately to 3–4 €/m^3 of pre-treated pig manure (i.e. following separation and nitrification/denitrification). In comparison, spreading pre-treated pig manure as a fertilizer costs about 5 €/m^3 in the nutrient intensive region of Flanders, making wetland systems a valuable alternative. Particular interest for further investigation regarding treatment wetlands for this type of application, goes to the role of recalcitrant dissolved organic matter and its impact on elevated COD concentrations which can occur even if BOD_5 concentrations remain well below discharge limits (<25 mg/L) and in the majority of observations even below detection limits (<4 mg/L).

References

Aquafin. (2013). *Jaarverslag 2013*. Retrieved from http://jaarverslag.aquafin.be/nl/jaarverslag-2013. (in Dutch).

Belgian Federal Government. (2010). *Structuur van de bevolking volgens woonplaats: oppervlakte en bevolkingsdichtheid*. Retrieved from http://statbel.fgov.be/nl/statistieken/cijfers/bevolking/structuur/woonplaats/oppervlakte_dichtheid. (in Dutch).

Boets, P., Michels, E., Meers, E., Lock, K., Tack, F.M.G., & Goethals, P.L.M. (2011). Integrated Constructed Wetlands (ICW): Ecological development in constructed wetlands for manure treatment. *Wetlands*, 31(4), 763–771.

Certipro. (2015). *Lijst van BENOR-vergunningen en –certificaten*. Retrieved from http://www.certipro.be/NL/Pages/watertreatment/benor-certificates.aspx?type=1. (In Dutch).

Coppens, J., Stas, S., Dolmans, E., Meers, E., Vlaeminck, S.E., & Buysse, J. (2013). *Onderzoeksrapport MIRA/2013/09, Begroting van stikstof- en fosforstromen in Vlaanderen*. Retrieved from: http://www.milieurapport.be/Upload/main/0_onderzoeksrapporten/2013/2013-09_Nutrientenstromen_EINDRAPPORT_finaal_20131121_MIRA_TW.pdf (In Dutch).

EEB. (2010). *10 years of the water framework directive: a toothless tiger? A snapshot assessment of EU environmental ambitions*. Retrieved from http://www.eeb.org/?LinkServID=B1E256EB-DBC1-AA1C-DBA46F91C9118E7D&showMeta=0

EU. (2013). *Commission staff working document accompanying the document "Report from the commission to the council and the European parliament"*. Retrieved from http://eur-lex.europa.eu/resource.html?uri=cellar:73d84fad-2f28-11e3-8d1c-01aa75ed71a1.0001.04/DOC_1&format=PDF

EU. (2014). *Factsheet on 2014–2020 Rural Development Programme of Flanders (Belgium)*. Retrieved from http://ec.europa.eu/agriculture/rural-development-2014-2020/country-files/be/factsheet-flanders_en.pdf

Lesage, E. (2006). *Behaviour of heavy metals in constructed treatment wetlands.* Ph. D thesis, Ghent University, Belgium.

Meers, E., Tack, F.M.G., Tolpe, I., & Michels, E. (2008). Application of a full-scale constructed wetland for tertiary treatment of piggery manure: monitoring results. *Water, Air, and Soil Pollution*, 193(1–4), 15–24.

MIRA. (2014). *Nitraat in grondwater in landbouwgebied*. Retrieved from http://www.milieurapport.be/nl/feitencijfers/milieuthemas/vermesting/nutrienten-in-water/nitraat-in-grondwater-in-landbouwgebied/. (In Dutch).

Rousseau, D.P.L., Vanrolleghem, P.A., & De Pauw, N. (2004). Constructed wetlands in Flanders: A performance analysis. *Ecological Engineering*, 23(3), 151–163.

Toet, S., Van Logtestijn, R.S.P., Kampf, R., Schreijer, M., & Verhoeven, J.T.A. (2005). The effect of hydraulic retention time on the removal of pollutants from sewage treatment plant effluent in a surface-flow wetland system. *Wetlands*, 25(2), 375–391.

Tyroller, L., Rousseau, D.P.L., Santa, S., & García, J. (2010). Application of the gas tracer method for measuring oxygen transfer rates in subsurface flow constructed wetlands. *Water Research*, 44(14), 4217–4225.

Van Oirschot, D. (2010). First certified small-scale treatment system based on a wetland, according to EN 12.566/3. In Proceedings of 12th IWA international conference on wetland systems for water pollution control, Venice, Italy. , London: IWA Publishing. 1614 pp.

VLAREM. (2016). *VLAREM II appendix – 5.3.1*. Retrieved from http://www.lne.be/themas/vergunningen/bestand/regelgeving/VLAREM-II-bijlagen_versie_VITO_pdf.zip. (In Dutch).

VMM. (2015). *Riolerings- en zuiveringsgraden per gemeente*. Retrieved from https://www.vmm.be/data/riolerings-en-zuiveringsgraden/riolerings-en-zuiveringsgraden-per-gemeente_januari-2015.pdf. (In Dutch).

Vymazal, J. (2002). The use of sub-surface constructed wetlands for wastewater treatment in the Czech Republic: 10 years experience. *Ecological Engineering*, 18(5), 633–646.

Vymazal, J. (2007). Removal of nutrients in various types of constructed wetlands. *Science of the Total Environment*, 380(1–3), 48–65.

Vymazal, J. (2009). The use constructed wetlands with horizontal sub-surface flow for various types of wastewater. *Ecological Engineering*, 35(1), 1–17.

Wallace, S.D., Knight, R.L. (2006). Small–scale constructed wetland treatment systems. London: Water Environment Research Foundation, IWA Publishing. 304 pp.

Xu, D., Xu, J., Wu, J., & Muhammad, A. (2006). Studies on the phosphorus sorption capacity of substrates used in constructed wetland systems. *Chemosphere*, 63(2), 344–352.