Chapter 3
Performance of Constructed Wetlands Treating Domestic Wastewater in Norway Over a Quarter of a Century – Options for Nutrient Removal and Recycling

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Abstract Norwegian constructed wetlands (CWs) that treat domestic wastewater are classified as horizontal subsurface flow constructed wetlands (HSFCWs). Over the years of continuous performance, the HSFCWs operating under cold climate conditions have shown a high and stable treatment efficiency with regard to the removal of organic matter (>90 % BOD), nutrients (>50 % N and >90 % P) and microbes (>99 % bacteria). The majority of Norwegian HSFCWs are categorised as small (<50 pe) on-site, decentralised wastewater treatment systems. The Norwegian systems consist of three fundamental elements: a septic tank, a pre-filter (i.e. an aerobic vertical flow biofilter) and a horizontal flow saturated filter/wetland bed. The first, primary treatment step begins in the septic tank from which effluents are pre-treated in the second step occurring in the pre-filter/biofilter section and further in the third, final step taking place in the filter bed/HSFCW. The first and third treatment steps are quite common in systems with CWs, but the pre-treatment in biofilter(s) is mainly known from Norway. The main purpose of using the pre-treatment phase is to supply air during the cold season, to enhance nitrification processes, and to reduce the load of organic matter before entering the filter/wetland bed. If constructed and maintained correctly, the biofilters alone can remove 90 % BOD and 40 % N. Various filter/CW beds have been introduced for treatment of domestic wastewater (as complete or source-separated streams) in Norway, but the most common feature is the use of specific filter media for high phosphorus (P) removal. A few Norwegian municipalities also have limits with respect to nitrogen (N) discharge, but the majority of municipalities use 1.0 mg P/l as the discharge limit for small wastewater treatment systems. This particular limit affects the P retention lifetime of the filter media, which varies from system to system depending on the filter media applied, the type of wastewater treated, and the system design and loading rates. An estimated lifetime of filter media with regard to P removal is

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J. Vymazal (ed.), *Natural and Constructed Wetlands*,
DOI 10.1007/978-3-319-38927-1_3

approximately 15–18 years for a filter/CW bed of a single household. After completing the lifetime, the filter media is excavated and replaced with new/fresh materials, allowing the system to operate effectively for another lifespan. Since the exploited media are P-rich materials, the main intention is their reuse in a safe and hygienic way, in which P could be further utilised. Therefore, the Norwegian systems can represent a complex technology combining a sustainable technique of domestic wastewater treatment and a bio-economical option for filter media reuse. This is a quite challenging goal for reclamation and recycling of P from wastewater. Thus, there are some scenarios of reusing the P-rich filter media as a complementary P fertiliser, a soil amendment or a conditioner, provided the quality is acceptable for utilisation in agriculture. Alternatively, the filter media could be reused in some engineering projects, e.g. green roof technology, road screening or construction of embankments, if the quality allows application in the environment. The core aspect of the reuse options is the appropriate quality of the filter media. As for the theoretical assumption, it should not be risky to reuse the P-rich media in agriculture. In practice, however, the media must be proven safe for human and environmental health prior to introducing into the environment.

Keywords Horizontal subsurface flow constructed wetlands (HSFCWs) • Nutrients • Pre-filter/biofilter • Filter media reuse

3.1 The State of the Art in a Nutshell

It has been a quarter of a century since the first wastewater treatment system employing constructed wetland (CW) was implemented at Haugstein farm, approximately 20 km southeast of Oslo, southeast Norway. The main purpose behind this implementation was to assess the ability of CW in treating domestic wastewater under cold climate conditions. The pioneering system was constructed with two wetland beds: one filled in with sand and the other with light expanded clay aggregates (LECA). As fast as the system revealed that it was well adopted with regard to climatic variations, plant assimilation and treatment efficiency, the popularity of such a nature-based treatment technology gained more interest. It turned out that filter/CW beds were widely implemented for treatment of different types of wastewater with respect to the origin, diversity of pollutants and specific treatment goals.

At present, there are generally two types of CWs adapted to wastewater treatment under Norwegian conditions, i.e. systems with surface and subsurface flow. Systems of the first type with free flow of water at the surface of the CW bed are commonly used for treatment of agricultural and/or urban (including road and tunnel) runoff, storm waters and landfill leachates. For treatment of domestic wastewater, in particular at decentralised locations, CWs with subsurface flow of water (underneath the surface of the filter bed) are the most popular in Norway. Furthermore, systems with horizontal flow have been commonly used; hence, the

Norwegian CWs are classified as horizontal subsurface flow constructed wetlands (HSFCWs).

Although various designs of CWs have been introduced for treatment of domestic wastewater in Norway, the most common feature is the use of specific filter media for high P removal. This is because phosphorus (P) is considered the main element triggering eutrophication in Norwegian waterways. Thus, its efficient removal is required for small, decentralised treatment systems. A few Norwegian municipalities also have limits with respect to nitrogen (N) discharge, in order to protect local groundwater or sensitive fjord areas; however, the majority of municipalities normally use 1.0 mg P/l as the discharge limit for small wastewater treatment systems. This particular limit affects the P retention lifetime of the filter media, which varies from system to system depending on filter media applied, the type of wastewater treated, and the system design and loading rate. After completing the lifespan, the filter media have to be excavated and replaced with new materials, allowing the system to operate effectively for another lifespan. Since the exploited media are P-rich materials, the main intention is not to waste them, but rather to reuse them in a safe and hygienic way, in which P could be further utilised. Alternatively, the media could also be reused as either soil conditioners or road constructing amendments.

The majority of Norwegian HSFCWs are categorised as small (<50 pe) decentralised, on-site wastewater treatment systems, but there is also a range of systems operating for a higher number of individuals. It is therefore quite difficult to provide an exact figure of total CWs treating domestic wastewater over the entire country. However, according to the latest statistical data (Statistics Norway 2014), there were 203 filter/CW beds in Norway (Fig. 3.1).

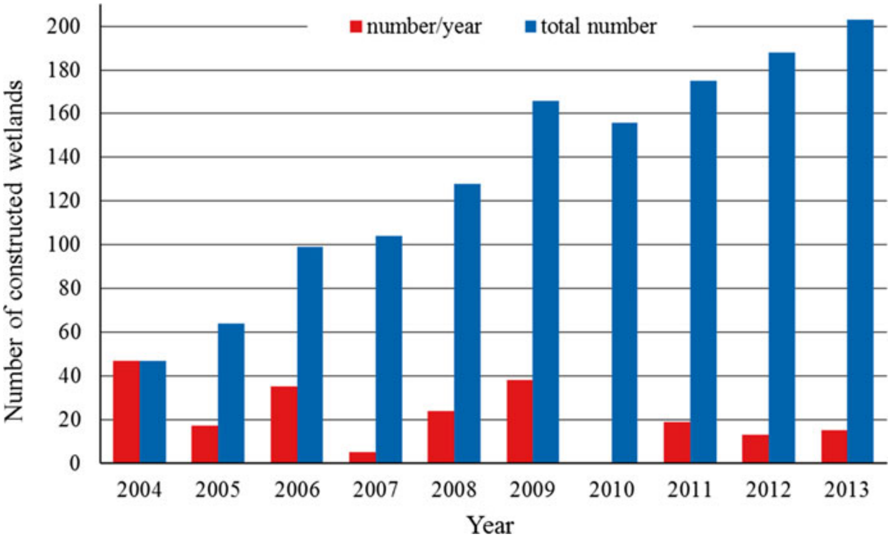

Fig. 3.1 Number of constructed wetlands and filter beds employed in small (<50 pe) systems treating domestic wastewater in Norway (Statistics Norway 2014)

This number, however, considers only the small systems, thus CWs serving for more than 50 pe are not included in these statistics. This is strictly related to the fact that one of the categories of Norwegian municipal wastewater treatment plants includes nature-based systems (212 in total number), thus also all the CWs operating for >50 pe (Statistics Norway 2014). In addition, it happens that not all treatment systems (especially the decentralised, on-site ones) are reported by municipalities, hence are not included in published documents (Statistics Norway 2014). It can therefore be estimated that the total number of CWs treating domestic wastewater in Norway is actually much higher than the reported figures.

Scientists from NIBIO have been actively involved in developing, designing, constructing and studying the range of small on-site, decentralised systems treating domestic wastewater in Norway, including long-term investigation of the first, pioneering CW in Haugstein. The results presented throughout this chapter in tables and figures that have no external references have been derived from the research database established by engineers and scientists from NIBIO.

3.2 General Characteristics and Design Principles

The main goal for all HSFCWs treating domestic wastewater in Norway is high nutrient and organic matter removal, with particular attention paid to phosphorus (P) and BOD reduction (>90 % in sensitive areas). A few municipalities have established limits with respect to nitrogen (N) removal, but the majority of municipalities use 1.0 mg P/l as the discharge limit. To achieve these limits, Norwegian systems have been designed with three fundamental treatment steps. The first (primary treatment) represents an anaerobic method, the oldest and most common in on-site treatment systems (Ntengwe 2005; Seghezzo et al. 1998), and occurs in a septic tank. The second (pre-treatment) is characterised by an aerobic phase carried out in a biofilter section. The third (final) treatment step takes place in a filter bed of HSFCW. Consequently, the typical CW system treating domestic wastewater in Norway consists of three principal elements: (1) the septic tank followed by (2) the pre-filter/biofilter with vertical unsaturated flow and (3) the subsequent saturated horizontal flow filter/wetland bed. The first and third treatment steps are quite common in systems with CWs, but the pre-treatment in biofilter(s) is mainly known in Norway, where it has been introduced for supporting the entire operation of the treatment system under cold climate conditions (Jenssen et al. 1991).

3.2.1 Septic Tank

A three-chamber septic tank with minimum volume of 4 m^3 was required for single households (5 pe producing 1 m^3 wastewater daily) in Norway (Miljø blad 2001b). This is no longer necessary as the Norwegian norm has been revised, and from 2013 prefabricated one-chamber septic tanks can be used. Yet, the highest number of

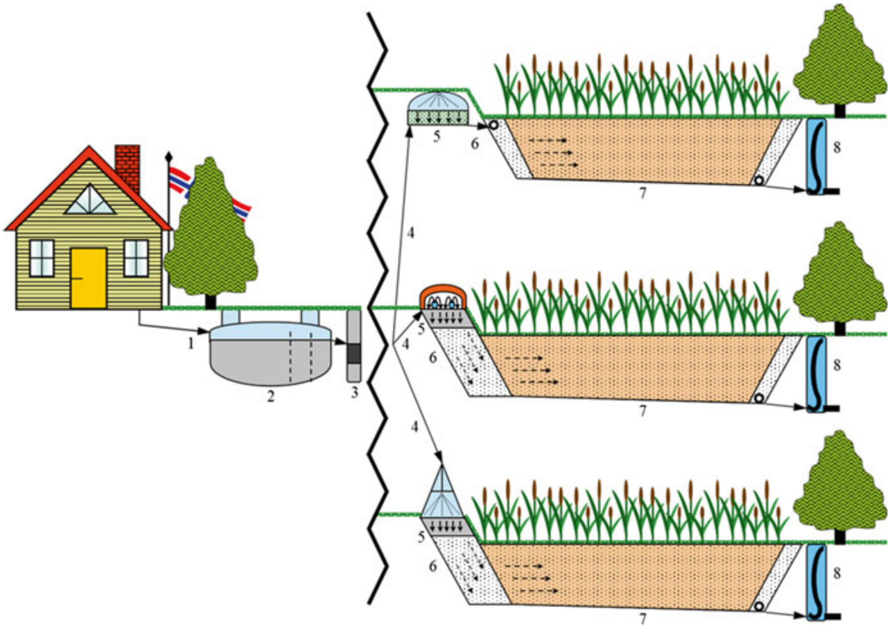

Fig. 3.2 General layout of the Norwegian HSFCW in three configurations where: *1* – inlet (domestic wastewater), *2* – three-chamber septic tank (the first treatment step), *3* – pump well, *4* – effluent from the septic tank, *5* – typical configuration of an aerobic pre-filter/biofilter (the second treatment step) constructed in dome (*top configuration*), infiltration bed (*middle configuration*) and shelter (*bottom configuration*), *6* – effluent from the biofilter, *7* – wetland bed with vegetation (the third treatment step), *8* – outlet (effluent from the entire system)

filter/CW beds was constructed with three-chamber septic tanks; hence this type of tank has been described here. The first chamber normally has a larger volume than the others, as is designed for the collection of sludge. It is estimated that 0.25 m^3 of sludge per pe during 1 year can be collected from households equipped with WC. Normally, there is an 18-h retention time for domestic wastewater in the septic tank before entering the next treatment steps. Effluent from the septic tank is first pre-treated by the pre-filter/biofilter units before entering the final treatment step in the filter/wetland bed. The effluent is normally pumped up from the tank and then pumped into the pre-filter/biofilter section. A high-pressure borehole peristaltic pump is used for dosing the septic tank effluent into the pre-treatment section. The pump is commonly installed in a well between the septic tank and the pre-filter section (Fig. 3.2).

3.2.2 Pre-filter/Biofilter

The main purpose of implementing the pre-filter/biofilter section was to supply air during the cold season and to enhance the nitrification processes improving N removal (Mæhlum et al. 1995). An additional reason was to pre-treat effluents from septic tanks through reduction of organic matter, thus avoiding possible clogging occurring in CWs (Mæhlum and Jenssen 1998). Furthermore, pre-filters decrease the load of these effluents into wetland/filter beds and thus a stable and high effect of treatment can be achieved (Miljø blad 2001a).

For the best performance of this treatment step, the septic tank effluent has to be distributed evenly onto the surface of the biofilter media. The effluent distribution can be performed either by infiltration pipes (placed in splashing capsules or covered by coarse materials, e.g. gravel and/or crashed stones) or by spray nozzles. The latter have been found to be more effective in providing an even distribution of the effluent over the whole biofilter media. Furthermore, use of the pre-filters with spray nozzles has revealed a higher treatment efficiency (Jenssen et al. 2005); thus, these so-called trickling biofilters became standard pre-filters used in Norwegian design of CW systems treating domestic wastewater.

The pre-filter constitutes a down (vertical) flow aerobic filter (biofilter) filled in with special media. It can be built in a dome, a tank or a sheltered bed (Fig. 3.2) depending on local conditions. The minimum depth of the pre-filter is 0.5 m. The depth is equal to the minimum height of the biofilter bed, if it is integrated with the front edge of CW (Fig. 3.2). For biofilters built in a separate units (domes or tanks), the minimum height is 0.6 m, due to the 0.1 m drainage zone for the effluent collected (Miljø blad 2001a).

To obtain a high treatment efficiency, the biofilter has to be built with an adequate surface area for receiving wastewater. The surface area is a dimensioning parameter and depends mainly on two factors: daily water consumption (l/pe/d) and hydraulic load (cm/d). According to the Norwegian guidelines (Miljø blad 2001a), the first factor is defined as 200 l/pe/d, while the second is 10 cm/d (100 l/m^2/d) or 20 cm/d (200 l/m^2/d) for infiltration or trickling biofilters, respectively. Based on these factors, the surface area in the standard pre-filters (trickling biofilters) can be estimated as 1 m^2/pe. However, the minimum surface area of one trickling biofilter should be at least 3 m^2 (Føllesdal 2005).

In general, wastewater discharged from one household (5 pe) should be treated by two pre-filters (minimum total surface area of 6 m^2). The number of pre-filters increases by one with the number of households; thus two households (10 pe) have three pre-filters, three households (15 pe) have four pre-filters, and so on (Føllesdal 2005). In some situations, e.g. when the local conditions limit available space, the surface area could be scaled-down. This, however, require recirculation of the effluent through the pre-filter section.

Hydraulic loading rates depend on the type of the pre-filter (i.e. infiltration or trickling biofilter, Fig. 3.2) and the type of treated wastewater. For the best performance of the standard pre-filters (trickling biofilters), the suggested maximum hydraulic loading rate is 20 cm/d (Miljø blad 2001a). Some studies, however, have revealed that high performance could also be achieved with higher loading rates of up to 30 cm/d (Heistad et al. 2006; Jenssen et al. 2005). The best treatment efficiency can be obtained if the loading is dispensed with fixed small doses, optimally 18–48 doses/d (Miljø blad 2001a). The spray nozzles (1–2 per biofilter), which are suspended over filter media, enable an even distribution of the septic tank effluent over the entire biofilter. The effluent flows further vertically down to the drainage zone at the bottom of the biofilter and, finally, the drained effluent runs off gravitationally to the inlet side of the third/final treatment step occurring in the filter/wetland bed (Fig. 3.2). In the case of separately built pre-treatment units, the drained effluent has to be transmitted gravitationally through a sealed pipe into the perforated distribution pipe (Fig. 3.2). This pipe can be placed in the upper layer of the inlet side in a mass of crushed stones or coarse gravel (10 mm in diameter, clean and free of ash, dust and fine particles) constituting the first part (approx. 0.6 m) of the filter/wetland bed (Miljø blad 2001a).

3.2.3 Constructed Filter/Wetland Bed

Depending on the design of the pre-filter/biofilter section, effluents can run directly into the underlying submerged basin of horizontal flow filter/wetland bed, or indirectly through the distribution pipe in the inlet side integrated with the saturated filter/wetland bed (Fig. 3.2). This is the largest element of the entire wastewater treatment system and has a retention time of 10 days (Miljø blad 2001a). The saturated bed is mainly constructed for P removal to achieve the discharge limit of 1.0 mg P/l (Heistad et al. 2006; Jenssen et al. 2005). For this purpose, the use of filter media with a high P-binding capacity is recommended (Miljø blad 2001a).

The filter/CW bed is an excavated basin of 0.9–1.0 m depth, screened/sealed/insulated at the bottom and edges with a watertight material (e.g. geomembrane made of polyethylene, PVC or bentonite) and filled in with the appropriate filter media. The entire screening of the basin can be avoided if the system is constructed on sites with clay soil (hydraulic conductivity $< 10^{-8}$ m/s) and where the groundwater table is permanently lower than 1.5 m, assuring adequate protection of groundwater from wastewater contamination (Miljø blad 2001a). In this case, however, the use of geotextiles is recommended to separate the filter media from the native soil. The bottom of the filter/CW bed needs to be built with a slight slope of 0.5–1 % between the inlet and outlet side of the bed, i.e. at 1:200–1:100 hydraulic gradient respectively (Miljø blad 2001a). The outlet side of the bed can be constructed in a similar manner as the inlet side. Thus, the perforated pipe collecting the effluent and transmitting it gravitationally into a well/manhole chamber can be installed (Fig. 3.2). The collecting pipe is placed at the bottom of the outlet side in a mass of crushed stones or coarse gravel (10–30 mm in diameter, clean and free of ash, dust and fine particles) constituting the last part (approx. 0.6 m) of the filter/wetland bed (Miljø blad 2001a). The entire bed is normally planted with macrophyte vegetation, in Norway typically with *Phragmites* spp. (common reeds) and *Typha* spp. (cattails). There are also some systems, in particular filter bed treatment systems, established without wetland vegetation at all.

3.2.4 Filter Media

Different media have been applied for construction of pre-filters and filter beds in on-site domestic wastewater treatment systems in Norway. The applied media replace native soils with gravel, sand, shell/coral sand, crushed limestone and lightweight aggregates (LWA). LWA are typical media used in Norwegian CW systems, and among them, the products with the brand name LECA® (light expended clay aggregates) and Filtralite® are the most frequently used (Søvik and Kløve 2005). In addition, shell sand products under the brand name Filtramar™ have been implemented on the commercial market.

The LWA filter media are normally applied for the second and third treatment steps, pre-filters/biofilters and filter/CW beds, respectively. These porous materials (with a large surface area of over 5000 m^2/m^3) are ideal media for biofilm growth. Specially developed, Filtralite® NR (N = normal density, R = round material) with a grain size of 2–4 mm is the most frequently used media in Norwegian biofilters. To avoid eventual clogging and formation of puddle over the surface of the biofilter, more coarse materials, e.g. Filtralite® NR with a grain size of 4–10 mm, could also be implemented in the upper 10–20 cm layer (Føllesdal 2005). The main function of filter media applied in filter/CW beds is an efficient P removal; hence, specially developed Filtralite®P (P = high phosphorus sorption capacity) has been widely applied in Norway. In principle, 8–10 m^3 of the filter materials per pe is projected; thus, 40 m^3 of filter media is normally applied in the system treating wastewater discharged from a single household (5 pe = 1 m^3 wastewater daily) equipped with a septic tank, pair of trickling biofilters and filter/CW bed (Miljø blad 2001a).

3.3 Overall Treatment Performance

The range of major pollutants in Norwegian domestic wastewater treated by small on-site, decentralised systems studied by scientists from NIBIO over the years is presented in Table 3.1. Although there is a quite a large variety in concentration rates of the contaminants and in the overall treatment performance, the removal of nutrients is relatively sufficient, especially the average P reduction below the Norwegian limit of 1.0 mg P/l.

An efficient treatment of domestic wastewater in on-site, decentralised systems relies on an effective performance of each and every treatment step in the entire system. Thus, sufficient removal of particles from wastewater hangs on the optimal operation of the septic tank; the necessary reduction in organic matter and N depends on the appropriate function of the pre-filter/biofilter section; while high removal of P and pathogenic microbes rests on vital activities occurring in the filter/CW bed. If all the treatment steps work effectively, then the treatment efficiency of the entire system can be expected to be relatively high.

Table 3.1 The range (min = minimum, max = maximum and st.d. = standard deviation) of contaminants (mg/l) in domestic wastewater entering selected small on-site treatment systems (inlet content) and in the effluents from these systems (outlet content)

	Inlet content				Outlet content			
Parameter	Min	Mean	St.d.	Max	Min	Mean	St.d.	Max
BOD	3	155	123	400	<2	52	43	130
COD	205	648	399	1980	<5	53	51	206
TSS	12	134	143	860	<2	41	39	120
TOC	37	121	63	250	3	24	20	57
P tot	0.22	9.3	5.4	28.6	0.01	0.16	0.28	1.4
N tot	6	80	39	153	7	39	28	103
$N\text{-}NO_2+NO_3$	0.04	0.12	0.11	0.20	0.11	3.2	4.1	12
$N\text{-}NH_4$	60	123	24	149	0.02	40	37	101
Cl	7	37	24	79	8	29	21	73
pH	6.9–7.9				10.1–>12.0			

Primary treatment occurring in the septic tank (through retention, sedimentation and digestion of organic matter settled as sludge) provides the most effective and undisturbed sedimentation of solids, eggs and (oo)cysts of some pathogenic intestinal parasites. The digestion process conducted by anaerobic bacteria defines the septic tank as a simple/preliminary biological treatment step (Paruch 2010).

The second treatment phase carried out in the pre-filter/biofilter section provides a high removal of organic matter, which can reach >99 % in terms of BOD reduction (Jenssen et al. 2010). In addition, the pre-filters/biofilters can efficiently nitrify and reduce ammonia concentrations (Heistad et al. 2006). It has been revealed that the pre-treatment section can remove up to 40 % of total N (Jenssen et al. 2005). As there is no sludge accumulation at the bottom of the pre-filter/biofilter units, denitrification can happen in the deeper, anoxic layers of a biofilm formed in the biofilter or in anaerobic sites of filter particles. The biofilter can also remove substantial P concentrations, but it becomes quickly saturated (depending on loading rates), then the major removal processes occur in the filter/wetland bed.

The final treatment occurring in the HSFCW can provide a high reduction of P of more than 90 % within the first 10 years of operation. In general, high P removal can be associated with high removal of bacteria and viruses (Schijven and Hassanizadeh 2000). It has been revealed that patches of positively charged aluminium (Al) and iron (Fe) oxides in Filtralite®P media can attract negatively charged viruses (Heistad et al. 2006). Furthermore, a high concentration of magnesium (Mg) and calcium (Ca) ions in these media may facilitate salt bridge effects between negatively charged surfaces (Heistad et al. 2009).

In addition to the main function of the specific filter media, the macrophyte vegetation also plays an essential role in the removal of different contaminants, in particular P and N (eutrophication-limiting nutrients in aquatic environments), through several mechanical, chemical and biological routes. These employ very complex processes accelerated by the natural synergies between the biologically active (with micro- and macro-organism interactions) ecosystems of soil, water, vegetation and atmosphere. The removal processes include retention, sorption, accumulation, plant uptake, photo degradation and microbial activities enhanced during the passage of wastewater through the rhizosphere. The developed root system expanded throughout the vegetated bed plays a substantial role in transporting contaminants, serving as pathways for gases, and moving particles (Scholz et al. 2002). Vegetated systems act as natural filters that hold particles and inhibit sediments against re-suspension by stabilising them within roots. Rhizomes of reeds create a natural barrier for parasite eggs, so they can be easily destroyed by antagonistic organisms (e.g. earthworms) settled in the filter beds (El-Khateeb et al. 2009; Mandi et al. 1996; Reinoso et al. 2008). Also, the numbers of the bacterial distribution on macrophyte roots sharply decrease within the first few metres along the horizontal flow in vegetated filters (Vymazal et al. 2001).

3.4 Recycling Options for Filter Media

To maintain a high treatment efficiency, the filter media have to be exchanged when the P concentration in the effluent exceeds the discharge limit (i.e. 1 mg P/l). An estimated lifetime of filter media is approx. 15 years for a bed of a single household when the inlet values are about 10 mg P/l (Jenssen and Krogstad 2002). In practice, however, many Norwegian systems have already exceeded the theoretical lifespan and the filter media have reached their P-sorption capacity, but they are still in continuous operation. There are two options for such systems: either to completely shut down the entire system or to re-establish it with fresh/new media replacement. Usually, the second option is considered; however, there are many uncertainties regarding dealing with the excavated/exchanged filter media. On the one hand, the used media are P-rich structural materials that may be utilised as soil amendments and conditioners. Results from laboratory-scale and pot experiments carried out in the Nordic countries demonstrate that P-rich filter media have a positive fertiliser and liming effect, thus could be considered for reuse as a plant fertiliser (Jenssen et al. 2010). On the other hand, reuse of these media has to be done in a safe and hygienic way, thus the media need to be considered as harmless and non-toxic for human and environmental health.

So far, to our knowledge, there have been limited data on the range of contaminants in filter media of CWs in Norway. This is perhaps due to the main focus being given to the effectiveness of these systems in wastewater purification; therefore their year-by-year performance was the main interest, not the fate of the exploited filter media. The initial survey on contaminants accumulated in filter media of the representative CWs in Norway was described by Paruch et al. (2007). The study was further extended and carried out in selected full-scale operating CWs; including the oldest CW in Norway, Haugstein (Table 3.2). The contaminants of concern were heavy metals (Cd – cadmium, Pb – lead, Cu – copper, Zn – zinc, Ni – nickel and Cr – chromium), thermotolerant coliform bacteria (TCB), *Salmonella* bacteria and parasite eggs, as defined in the Norwegian regulation on materials applied in cultivated areas (FOR 2003).

Table 3.2 General characteristics of four selected full-scale operating CWs in Norway

CWs	Construction year	Number of persons/facility connected	Type of filter media
Haugstein	1991	7/household	Sand and LECA®
Tveter	1993	7/household	LECA®
Holt	1999	12/household	Filtralite®P
Dal	2000	39/primary school	Filtralite®P

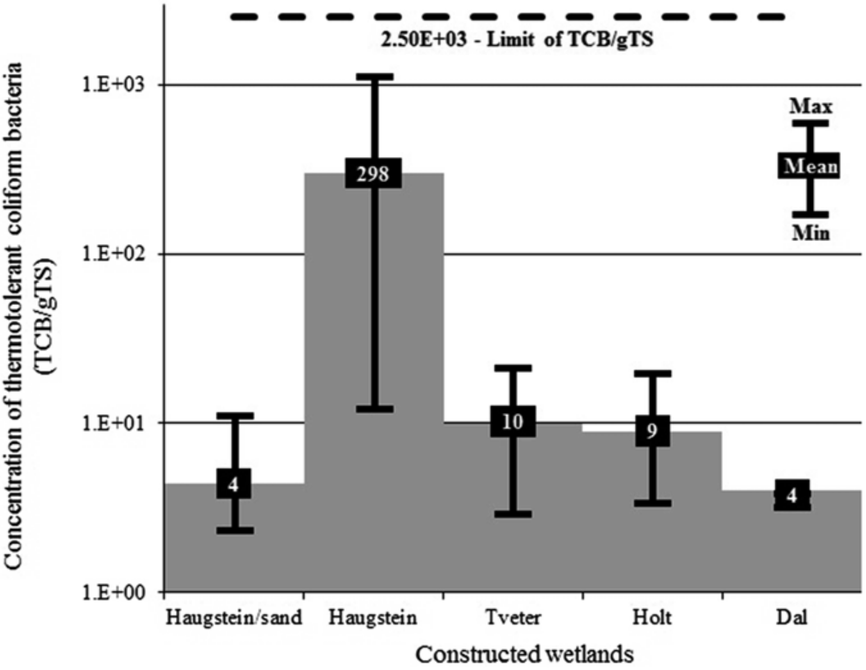

Fig. 3.3 The range of concentrations (min = minimum, mean and max = maximum) of thermotolerant coliform bacteria (TCB/g TS) in filter media of selected constructed wetlands and the limited number for these bacteria in materials applied in cultivated areas in Norway, i.e. 2500 TCB/g TS

The commonly applied filter media are porous materials with a large surface area, which makes them ideal media for biofilm growth. These porous media can harbour microorganisms, yet the mean TCB concentrations in materials tested from four different treatment systems did not exceed the upper limit of 2500 TCB/g TS (Fig. 3.3) set for materials applied in cultivated areas in Norway (FOR 2003). In addition, the survey on the presence of pathogenic microbes in the specific LWA filter media of full-scale operating CWs did not reveal any contamination with virus indicators (FRNA phage MS2 and phi X174), *Salmonella* and parasite eggs (Paruch et al. 2007).

The tested filter media demonstrated a relatively low sorption capacity for most of the heavy metals tested (Table 3.3), showing that their concentrations did not exceed the maximum permissible contents of heavy metals in the materials applied in cultivated areas in Norway (FOR 2003). Theoretically, domestic wastewater from

Table 3.3 Average concentrations of heavy metals in filter media (mg/kg TS) at the inlet and outlet sides of selected constructed wetlands (CWs) and the acceptable maximum contents of these metals in materials applied in cultivated areas (class 0 – no restrictions, class I – 40 t/ha/10 years, class II – 20 t/ha/10 years) and nonproductive green areas (class III – application every 10 years with restriction to cultivation of neither food crops nor fodder crops) in Norway (FOR 2003)

CWs	Quality classes	Heavy metals (mg/kg TS)					
	From 0-highest to III-lowest	Cd	Pb	Cu	Zn	Ni	Cr
	0	0.4	40	50	150	20	50
	I	0.8	60	150	400	30	60
	II	2	80	650	800	50	100
	III	5	200	1000	1500	80	150
Haugstein/sand							
Inlet	0	0.4	9	18	40	14	21
Outlet	0	0.4	7	15	40	16	22
Haugstein							
Inlet	0/II(Cr)/III(Ni)	0.4	4	26	54	52	91
Outlet	0/I(Ni)	0.4	5	22	56	30	39
Tveter							
Inlet	0/I(Ni)	0.4	8	18	74	24	35
Outlet	0	0.4	7	36	38	19	26
Holt							
Inlet	0/III(Ni and Cr)	0.4	4	22	44	56	109
Outlet	0/II(Ni and Cr)	0.4	4	21	43	37	69
Dal							
Inlet	0/I(Ni)	0.4	5	22	24	28	25
Outlet	0/II(Ni and Cr)	0.4	4	24	24	49	66

common households should not carry high concentrations of heavy metals, yet continuous operation of CWs treating wastewater may cause an accumulation of some metals over time.

As shown in Table 3.3, the contents of Cd, Pb, Cu and Zn in filter media did respond to the concentrations of these metals defined for the highest quality class of materials applied in cultivated areas in Norway. The contents of Ni and Cr at the inlet sides of two CWs (Haugstein and Holt) slightly exceeded their maximum acceptable concentrations defined for quality class II in materials applied in cultivated areas (Table 3.3). However, these contents were still within the maximum permissible concentrations of Ni and Cr in materials applied exclusively in nonproductive green areas (i.e. not cultivated for food- and/or fodder crops). On the other hand, materials collected from the outlet sides of CWs did not reveal concentrations of all the metals tested higher than the maximum permissible contents for materials applied in cultivated areas (Table 3.3). It could therefore be assumed that these filter media were suitable for reuse in terms of contaminant contents defined by Norwegian regulations. However, other pollutants should also be considered prior to the reuse options, in particular emerging contaminants present in domestic wastewater, e.g. pharmaceutical-derived compounds. Pharmaceutical and personal care products

(PPCPs) are commonly used nowadays; thus their presence in water and wastewater cannot be neglected. For instance, Bergersen et al. (2012) traced citalopram and sertraline (the most commonly used nervous system drugs in Norway) in sewage sludge, which indicates that these drugs must also be present in wastewater. Filtralite® media have proved effective in PPCPs removal, achieving over 80 % efficiency (Matamoros et al. 2009). However, the fate of PPCPs in these well-performed filter media was never considered, thus the contamination effect of these media cannot entirely be stated.

Polycyclic aromatic hydrocarbons (PAHs) are the other water pollutants of environmental importance, because of their carcinogenicity and mutagenicity (Nkansah et al. 2012). There is a recent global concern about the increase in PAHs' contamination of water. The PAHs detected in highest concentrations in drinking water are fluoranthene, phenanthrene, pyrene and anthracene. Since they are in drinking water, they are also expected in wastewater; therefore, PAHs removal by on-site treatment systems should be highly considered. So far, this has been tested in laboratory studies, which revealed that phenanthene, fluoranthene and pyrene can effectively be removed from water during batch sorption experiments using LECA as a sorbent (Nkansah et al. 2012). Physical sorption was the main mechanism that governed the removal process, which on the other hand caused the contamination of LECA filters.

All these examples demonstrate a high performance of LWA filter media with regard to the removal of different micropollutants, but the fate of these contaminants and their effect on the filter media must also be extensively investigated. This is of high importance for the reuse options of the exploited media from CWs treating domestic wastewater. It has been revealed that, even if the media are not highly contaminated, e.g. with faecal indicator bacteria – *Escherichia coli* (*E. coli*), this can drastically change during the storage period of these media (Paruch 2011). *E. coli* could survive and re-grow from relatively low initial concentrations and further persist in the specific LWA–Filtralite®P media for an extended period of time, over 14 months (Paruch 2011).

3.5 Conclusions

The concept of implementation of CWs in Norway was to imitate the natural ecosystems in soil media and wetlands with respect to their role in environmental pollution control through several mechanical, chemical and biological routes. Over the years of continuous performance, the treatment systems with filter/CW beds operating under cold climate conditions have shown a high and stable treatment efficiency regarding organic matter (high reduction of BOD and COD), nutrients (high P-binding capacity) and pathogens (high removal rates of viruses and bacteria). The removal efficiency of the main pollutants in treatment systems employing HSFCWs is relatively high, >90 % BOD, >50 % N, >90 % P and >99 % bacteria, providing that the systems are based on an appropriate design according to Norwegian recommendations. Therefore, HSFCWs are one of the most efficient nature-based treatment systems in Norway with respect to removal of contaminants from domestic wastewater.

The Norwegian systems represent a sustainable technique of domestic wastewater treatment and a bio-economical option for filter media reuse. This is a challenging goal to reclaim and recycle P from wastewater. Thus, there are some options of reusing the P-rich filter media as a complementary P fertiliser, a soil amendment or a conditioner, provided the quality is acceptable for utilisation in agriculture. Alternatively, the filter media could be reused in some engineering works (e.g. growth media in urban greening projects, green roof technology, road screening technics or construction of embankments), if the quality allows application in the environment. Therefore, the core aspect of the reuse options is the appropriate quality of the filter media. As for the theoretical assumption, it should not be risky to reuse the P-rich media. In practice, however, they must be proven safe for human and environmental health prior to introducing into the environment.

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