

## **Greywater Treatment in combined Biofilter/Constructed Wetlands in Cold Climate**

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### **Keywords**

greywater, biofilter, constructed wetland, cold climate

### **Abstract**

In Norway systems consisting of an aerobic biofilter followed by a subsurface horizontal flow constructed wetland has been very successful in reducing organic matter, indicator bacteria, nitrogen and phosphorus in greywater. Because of phosphate free detergents are used in Norway and no toilet waste is included, the average influent total phosphorus concentrations (measured as septic tank effluent-STE) are about 1mg P/l and the average influent total nitrogen concentrations are in the range 8-10 mg N/l. The aerobic biofilter prior to the wetland is essential to remove BOD in a climate where the plants are dormant during the cold season. When combined with a horizontal flow constructed wetland the concentrations of indicator bacteria in the effluent meets European standards for swimming water quality. The effluent concentrations for phosphorus are generally < 0.2 mg P/l and for nitrogen < 5mg N/l. The combined biofilter /constructed wetland systems require 1-3m<sup>2</sup> surface area per person. The compact design opens for urban use.

### **Introduction**

Norway has substantial experience from using source-separated systems for wastewater treatment (Jenssen and Skjelhaugen 1994, Jenssen 1996, 1999, 2001). In traditional sewer systems greywater constitutes 60-80% of the wastewater volume flow. In a recycling system based on source separation of wastewater fractions, water saving or dry toilets are used, hence, the greywater volume increases to >90% of the total wastewater flow. The toilet waste contains the majority of the nutrients and only 10% of the nitrogen, 26% of the phosphorus and 21% of the potassium is found in the greywater (Vinnerås 2002). Nutrient removal then becomes a minor issue. However, greywater may contain more than 50% of the organic matter in wastewater (Rasmussen et al. 1996) and a substantial amount of bacteria and viruses (Ottosen and Stenström 2002). Systems that can remove organic matter and pathogens are therefore needed in order to facilitate discharge or reuse of the greywater.

The extent of greywater treatment will depend on the final discharge and use of the water. If discharged to the sea, no treatment or maybe only a primary treatment step, is required. If discharged to lakes or rivers a secondary treatment step is often needed. Before discharged to streams or use in irrigation or groundwater recharge, the hygienic parameters must be reduced. For in-house reuse and drinking water, sophisticated tertiary treatment may be necessary. Wherever natural conditions allow, soil infiltration is a cost-effective option for greywater treatment (Westby et al. 1997). Norway has developed its own set of sizing and design criteria for greywater soil infiltration and sand filter systems (Jenssen and Siegrist 1991, MD 1992). This

paper describes design details and performance of biofilter/constructed wetland systems for greywater treatment in cold climates.

### Greywater composition

Representative data for wastewater production and composition on the household level are scarce and more data are needed to reliably predict the pollution potential from greywater. Rasmussen et al. (1996) performed a literature survey of greywater composition and found total phosphorus concentrations varying from 1,4 – 18,1 mg/l. The highest concentration is from Sweden (Olsson et al. 1968). In Olsson's study, it was stated that the detergent contributed with 2,5 g P/person and day or 912 g/person and year, this alone explaining the high phosphorous concentration. The total nitrogen varied from 6,7– 42 mg/l. Vinnerås (2002) has studied the present day wastewater composition in Sweden and showed that heavy metals in greywater seem to have decreased over the last years, but the mass discharge of nitrogen and phosphorus is somewhat underestimated compared to Naturvårdsverket (1995). After 1997 more data on greywater composition has accrued in Norway due to building of several larger systems. It is therefore interesting to compare some data on greywater composition (tab. 1).

Source	Phosphorus		Nitrogen	
	g/p and year	mg/l	g/p and year	mg/l
Torvetua*	58	1,07	406	7,1
Kaja*	56	0,97	470	8,2
Vinnerås 2002	190	5,0	500	13,2

\*Measured in septic tank effluent (STE)

**Table 1.** Mass (g/person and year) and concentrations (mg/l) in greywater.

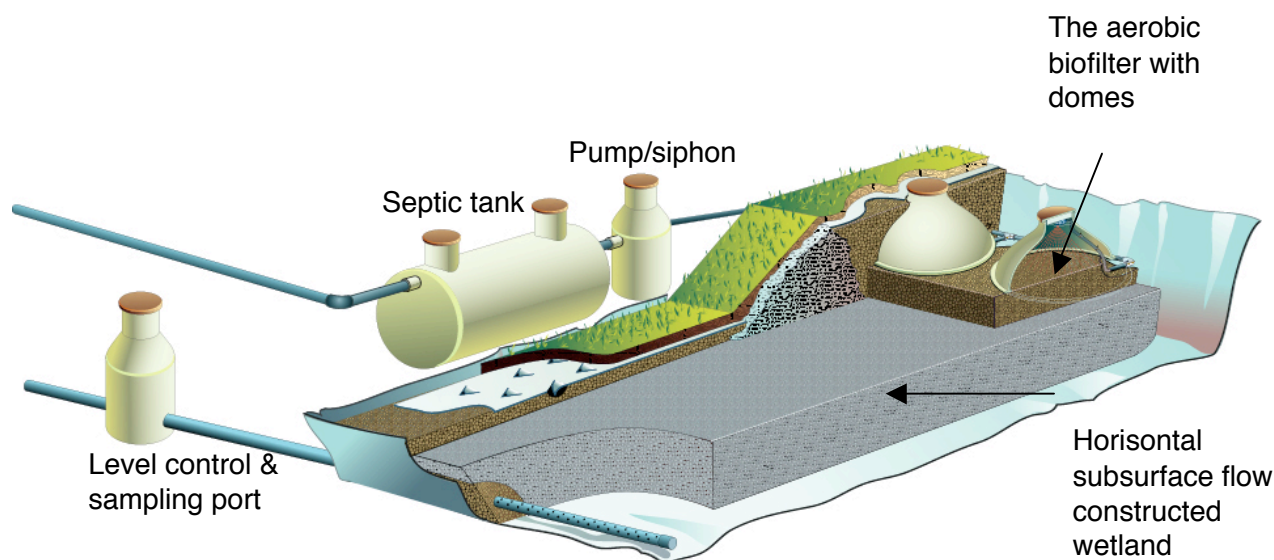
The data from Kaja and Torvetua in Norway are based on average flows and adjusted to 100% presence assuming 70% of the wastewater production occurring at home. For nitrogen the values from Torvetua and Kaja are somewhat lower than the Swedish values (Vinnerås 2002), however for phosphorus the Norwegian values are only 1/3 of the Swedish. The Norwegian values are based on STE. 5 - 20 % removal of nitrogen and phosphorus may occur in the septic tank (Pell and Nyberg 1985), hence, the difference in mass nitrogen may be due to the septic tank. The most probable reason for the difference in phosphorus content is the cloth- and dishwashing detergents. In Norway the majority of the cloth- and dishwashing detergents sold are phosphate free, whereas in Sweden they contain phosphorus.

When looking at the average concentrations of Norwegian greywater in samples taken after 1996, the average STE concentrations are 1,03 mg P/l for total phosphorus and 8,4 mg N/l for total nitrogen. These samples reflect the greywater composition from nearly 200 people. This means that the nitrogen meets the WHO drinking water standards of 10mg/l without any treatment. The Norwegian discharge consent for total phosphorus for many small chemical precipitation plants releasing their effluent to inland waterways is 1 mg N/l. In many cases greywater meets also this requirement with no or only primary treatment.

### Biofilter and horizontal flow construed wetlands - design and performance

The general concept (fig. 1) consists of pre-treatment of the wastewater in a septic tank, pumping to a vertical down-flow single pass aerobic biofilter followed by a subsurface horizontal-flow porous media filter. The biofilter may be integrated (as in fig.1) or located

separate from the horizontal flow section. The wetland section is usually vegetated with common reed (*Phragmites*). Evaluation of the role of plants in these systems when treating wastewater (including toilet waste), both in field and mesocosm scale systems, showed that the root-zone had a positive effect on N-removal, but no significant effect on P and BOD removal (Zhu 1998, Mæhlum and Stålnacke, 1999). Some of the later systems have therefore been built with grass over an insulating soil cover. The grass-covered systems do not fulfil the strict definition of a wetland, although the filter is water saturated.



**Figure 1.** The latest generation of constructed wetlands for cold climate with integrated aerobic biofilter in Norway.

### The aerobic biofilter

The biofilter (fig. 1) is covered by a compartment (e.g. a hemispherical dome) which facilitates spraying of the STE over the biofilter surface. The biofilter has a standard depth of 60 cm and a grain size within the range 2 – 10 mm is recommended. In Norway light weight aggregate (LWA) in the range 2 - 4 mm is the most common filter media, but gravel or other type media in the above size range may be used. The effect of filter depth on removal of BOD and bacteria in LWA and sand filters was studied by Rasmussen et al. (1996). The study concluded that BOD removal was independent of filter depth for LWA filters in the range 20 - 60 cm, but the bacteria removal was lower for the shallow filter depth.

Biofilters and constructed wetlands using light weight aggregates (LWA) or similar porous media are pioneered in Norway (Heistad et al. 2001, Jenssen and Krogstad 2002, Mæhlum and Jenssen 2002). The single pass biofilter aerates the wastewater and reduces BOD and bacteria. Using such biofilters for treating greywater more than 70% BOD reduction and 2-5 log reduction of indicator bacteria has been obtained at a loading rate for greywater up to 115 cm/d. Assuming a greywater production of 100 liters/person/day a biofilter of 1 m<sup>2</sup> surface area can treat greywater from about 10 persons, hence, very compact biofilters can be made. Clogging has not been observed even at loading rates exceeding 100cm/d, however, earthworms are observed living in the biofilter. Their grazing of the biofilm probably reduces clogging and

enhances the hydraulic capacity of the filter. The key to successful operation of the biofilter is uniform distribution of the liquid over the filter media and intermittent dosing (Heistad et al. 2001). In order to further improve the quality of the effluent, the biofilter can be followed by a subsequent sandfilter or a constructed wetland (fig. 1).

### The horizontal subsurface flow constructed wetland

According to the Norwegian guidelines (Gaut and Mæhlum 2001) the recommended depth of the horizontal subsurface flow constructed wetland is minimum 1 m. This is more than suggested in other guidelines (Vymazal et al. 1998, Kadlec et al. 2000). The reason is the cold climate. In Norway the systems are sized so that the upper 30cm of the system can freeze while still leaving sufficient hydraulic capacity to transport the water below the frozen zone. The final geometry (length, width) of a system is based on hydraulic considerations, but for systems treating combined grey- and blackwater, sizing also depends on the phosphorus sorption capacity of the media. For commercial systems treating greywater the resulting surface area is 2-3 m<sup>2</sup>/person. For systems treating combined grey- and blackwater the recommended surface area is normally in the range 7-9 m<sup>2</sup>/person. In experimental systems treating combined black- and greywater and for greywater systems only, more compact designs are being examined. All present systems in Norway are built with an aerobic biofilter preceding the horizontal subsurface flow constructed wetland (fig. 1). Some systems use sand in the horizontal flow section, but the majority of the systems in Norway use light weight aggregates (LWA) both in the biofilter and the horizontal flow section.

### Combined aerobic biofilter/constructed wetland systems

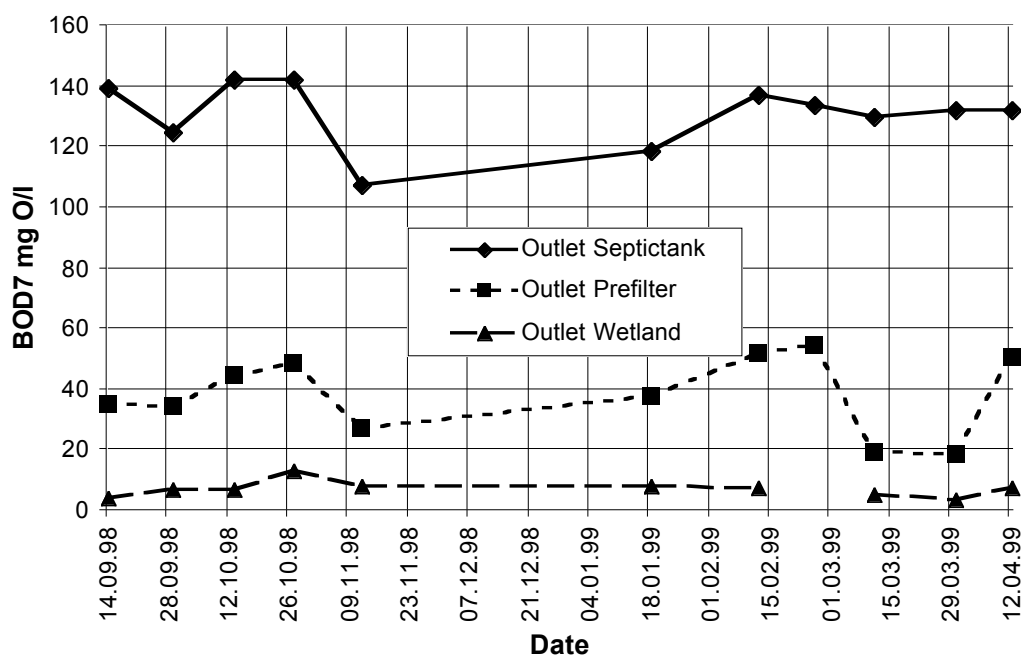
Three large combined biofilter/constructed wetland systems are in operation in Norway (tab. 3) The first system built according to the configuration in fig. 1 is the plant at Kaja that treats greywater from student dormitories at the Agricultural University of Norway (Table2). The Kaja plant has 2-4mm LWA (Filtralite<sup>TM</sup>) in both the biofilter and the horizontal flow wetland section.

Parameter	Average concentration out of each unit				Percent removal % Biofilter	Percent removal % Wetland	Total removal % Biofilter and Wetland
	Unit	Outlet Septic tank	Outlet Prefilter	Outlet Wetland			
pH		6,72	6,78	7,43			
Total phosphorous	mg P/l	0,97	0,32	0,07	67,0	78,1	92,8
Ortho phosphate	mg P/l	0,56	0,10	0,04	82,1	60,0	92,9
BOD <sub>7</sub>	mg O/l	130,7	38,2	6,90	70,8	81,9	94,7
Total nitrogen	mg N/l	8,20	5,00	2,50	39,0	50,0	69,5
Ammonium	mg N/l	3,2	2,4	2,3	25,0	4,2	28,1
Nitrate	mg N/l	<0,03	<0,03	<0,03			
Termotol. Colif. Bacteria	TCB /100 ml	106	10 <sup>3</sup> -10 <sup>5</sup>	0-10 <sup>3</sup>			

**Table 2.** Average concentrations and treatment performance (%) for the Kaja greywater treatment plant, fall 1998 and spring 1999 (n = 11).

Tab. 2 shows the performance of the Kaja system during its second year of operation. For total phosphorus and total nitrogen the effluent from the biofilter is very low. However, in order to reduce BOD<sub>7</sub> to below 10mg O/l, and to meet the present European requirement with respect to indicator bacteria in swimming water (<1000 termotolerant coliform bacteria/100ml) the horizontal subsurface flow wetland is needed. With a retention time of 6-7 days in the wetland

(Gulbrandsen 1999) the fluctuations in the outflow concentrations are small (fig. 2). Fig. 2 also shows that the BOD removal does not vary significantly with season. This may be attributed to the long retention time, but also the high greywater temperatures. During the winter the STE temperatures varied from 10-15°C and the temperature drop through the wetland section was 2-3°C (Gulbrandsen 1999). Nitrate is not detected. This may indicate that nitrification does not occur or that the produced nitrate is immediately denitrified.



**Figure 2.** BOD<sub>7</sub> concentrations vs. time in the STE, biofilter effluent and wetland effluent.

The high phosphorus sorption of the system (tab. 2) is due to the sorption capacity of the LWA used. Phosphorus sorption in the biofilter is only expected in the initial years. The wetland has a much higher total sorption capacity than the biofilter because of more volume. With the type of LWA used high phosphorus removal can be expected for 10-15 years.

The Kaja system is now running on its 6th year and no decline in phosphorus or nitrogen removal is observed. The last winter the BOD<sub>7</sub> was <3mg/l in all 3 samples in the outlet which indicate that the performance regarding BOD<sub>7</sub> may have improved. The Termotolerant Coliform Bacteria (TCB) counts in the outlet are generally below 100 TCB/100 ml and 7 out of 21 samples have shown 0 TCB/100ml.

The two treatment systems at Torvetua (42 condominiums) and Klosterenga (33 apartments) show very similar treatment values to the Kaja system (tab. 3).

System	Persons connected	Built year	TP		TN		COD		BOD <sub>7</sub> <sup>a</sup>		TCB <sup>b</sup>
			%	Cout	%	Cout	%	Cout	%	Cout	
Kaja	48	1997	94	0,05	70	2,6	94	15,8	94	5,6	sw
Torvetua	140	1998	79	0.21	60	2.2	88	41,0	97	5,5	sw
Klosterenga	100	2000		0,03		2.5		19,0			0

a) 7-day BOD is standard in Norway, b) Termotolerant coliform bacteria

sw = swimming water quality < 1000 TCB/100ml

**Table 3.** Average outlet concentrations and treatment performance (%) for 3 combined biofilter/constructed wetland systems. Average over total service time.

At Klosterenga, in the city of Oslo, the greywater is treated in the courtyard of the building. The space required for this experimental system is about 1 m<sup>2</sup>/person, and the treatment area is also used as a playground. The compact design is due to making the horizontal flow section 1,8m deep instead of the standard 1m, thus saving area and still having sufficient porous media volume in the horizontal flow section. Additional aeration, in the summer season, is provided by a flow-form system (Wilkes1980). No inlet samples are presently available at Klosterenga. The outlet samples show better performance with respect to phosphorus and bacteria than the systems at Kaja and Torvetua (tab. 3). This is due to a new LWA, FiltraliteP<sup>TM</sup>, which has very high phosphorus sorption and bacteria reduction capabilities. It is estimated, assuming similar inlet phosphorus concentrations as for Kaja and Torvetua, that saturating the wetland media with phosphorus will last more than 40 years at Klosterenga. With such high qualities of the effluent water, as shown in tab. 3, the need for a secondary sewer collection system is reduced because local streams or water bodies can be used for receiving treated water even in urban areas.

The excellent effluent quality (tab. 2 and 3) facilitates reuse of the water for irrigation, groundwater recharge or for in-house applications. For flushing toilets and car wash it may be possible to use the effluent water (tab. 3) without further treatment. However, recent results show that greywater may contain virus and bacterial pathogens that are not represented by the indicator bacteria (Ottosen and Stenström 2002). This may call for further treatment before use as suggested above. In order to upgrade to drinking water quality or for washing, microfiltration, reverse osmosis or carbon filtration may be needed as a single step or in combination.

## Conclusion

A combined vertical flow biofilter followed by a horizontal flow wetland filter is developed. More than 70% BOD removal and up to 5 log reduction of indicator bacteria is possible in the single pass porous media biofilters using about 0,1m<sup>2</sup> surface area/person. For the combined biofilter /constructed wetland system the total area requirement is 1-3 m<sup>2</sup>/ person and the effluent meets European swimming water standards with respect to indicator bacteria and WHO drinking water standards with respect to nitrogen. The low area requirement of the system and the high effluent quality facilitates use in urban settings, discharge to small streams or open waterways and subsequent treatment producing water for in-house use.

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