NI Project 02056
Wastewater Treatment in Filter Beds

Common Report from all Pilot Plants

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This project was carried out with support and funding from the Nordic Innovation Centre (NICe). Nordic Innovation Centre is the Nordic Council of Ministers' single most important instrument for promoting an innovative and knowledge-intensive Nordic business sector.

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Summary

This report gives an overview of the experiences and results from the sub projects with pilot plants in Denmark, Finland, Sweden and Norway, in the project **Wastewater Treatment in Filter Beds**. The project has been run with founding from Nordic Innovation Centre.

The pilot plants have been built as filter beds with pre filter and the plants have treated wastewater from single houses in rural areas. The inlet concentrations have been varying a lot but still the outlet concentrations have been low.

Average treatment efficiencies are 99 % for total phosphorus, about 50 % for total nitrogen and about 85 % for COD (organic matter). If expelling the results from the start up period where the biofilm is under establishing, the treatment efficiency for organic matter will be over 90%.

A Nordic guideline for design of treatment plants is worked out on basis of the experience from this project. The complete guideline is in appendix 3.

The regulations and demands on wastewater treatment in rural areas are given for each of the Nordic countries.

0.0 Introduction

The project “Wastewater Treatment in Filter Beds” has been run with contribution from Nordic Innovation Centre. The project has run from October 2002 to June 2005.
Totally 15 different universities, institutes and firms have taken part in the project from all the Nordic countries. A list of participants can be found in appendix 1.

Sub projects in each of the countries Finland, Sweden, Norway and Denmark are accomplished with building of pilot plants of the type Filter Beds with Pre Filter and the pilot plants are thoroughly followed-up by the sub project managers.

The sub projects were managed by:

- Finnish Environment Institute (FEI/SYKE) in Finland
- Stockholm Vatten in Sweden
- Norwegian Centre for Soil and Environmental Research (Jordforsk) and Norwegian University of Life Science (UMB) in Norway
- Aarhus University in Denmark

This common report from the pilot plants is put together by the project manager Magnhild Føllesdal, maxit Group. The results from each sub project are reported more in detail in seperate reports, all available on the internet on www.filtralite.com:

- ***Report from the pilot plants in Finland***, Riikka Vilpas (SYKE),Matti Valve (SYKE), Satu Räty (maxit Oy)
- ***Wastewater Treatment in Filter Beds – Evaluation of two onsite treatment plants,*** Daniel Hellström and Lena Jonsson (Stockholm Vatten)
- ***Wastewater Treatment in Filter Beds***, ***Report from pilot plant Hvitsten, Norway***, Trond Mæhlum and Jens Chr. Køhler (Jordforsk)
- ***Results and experiments from the two pilot plants at Norderås in Norway***, Lasse Vråle, Arve Heistad, Petter Jenssen (Norwegian University of Life Science)
- ***Wastewater Treatment in Filter Beds, Results from the pilot plant DK1 at Mørke, Denmark,*** Carlos A.Arias and Hans Brix (University of Aarhus)
- ***Wastewater Treatment in Filter Beds, Results from the pilot plant DK2 at Friland, Denmark,*** Carlos A.Arias and Hans Brix (University of Aarhus)

The project has also looked into reuse of phosphorus, contamination of heavy metals and bacteria in the used filter material and further development of the filter material, Filtralite P. The reports from these sub projects are:

- ***Wastewater Treatment in Filter Beds: Reuse of filter material,*** Anna-Mari Nyholm, Markku Yli-Halla, Pekka Kvistö (MTT, Agrifood Research Finland)
- ***Heavy metals accumulation and hygienic indication in subsurface flow constructed wetlands,*** Adam M. Paruch, Tore Krogstad, Petter D. Jenssen, Gunnar Stensen (Norwegian University of Life Sciences)
- ***Material Development,*** Torgeir Saltnes, Magnhild Føllesdal (maxit Group AB)

1.0 Design

The pilot plants in this project have been designed mainly after the Norwegian design guideline (VA Miljøblad no 49 “Våtmarksfiltre”). An overview of the design of all the pilot plants is given in table 1.

The treatment system is built up with a septic tank, pump well, a pre filter with nozzles spreading the wastewater over the surface of the filter, a submerged filter bed and outlet well as shown in figure 1.

Pictures from all pilot plants can be found in appendix 2.

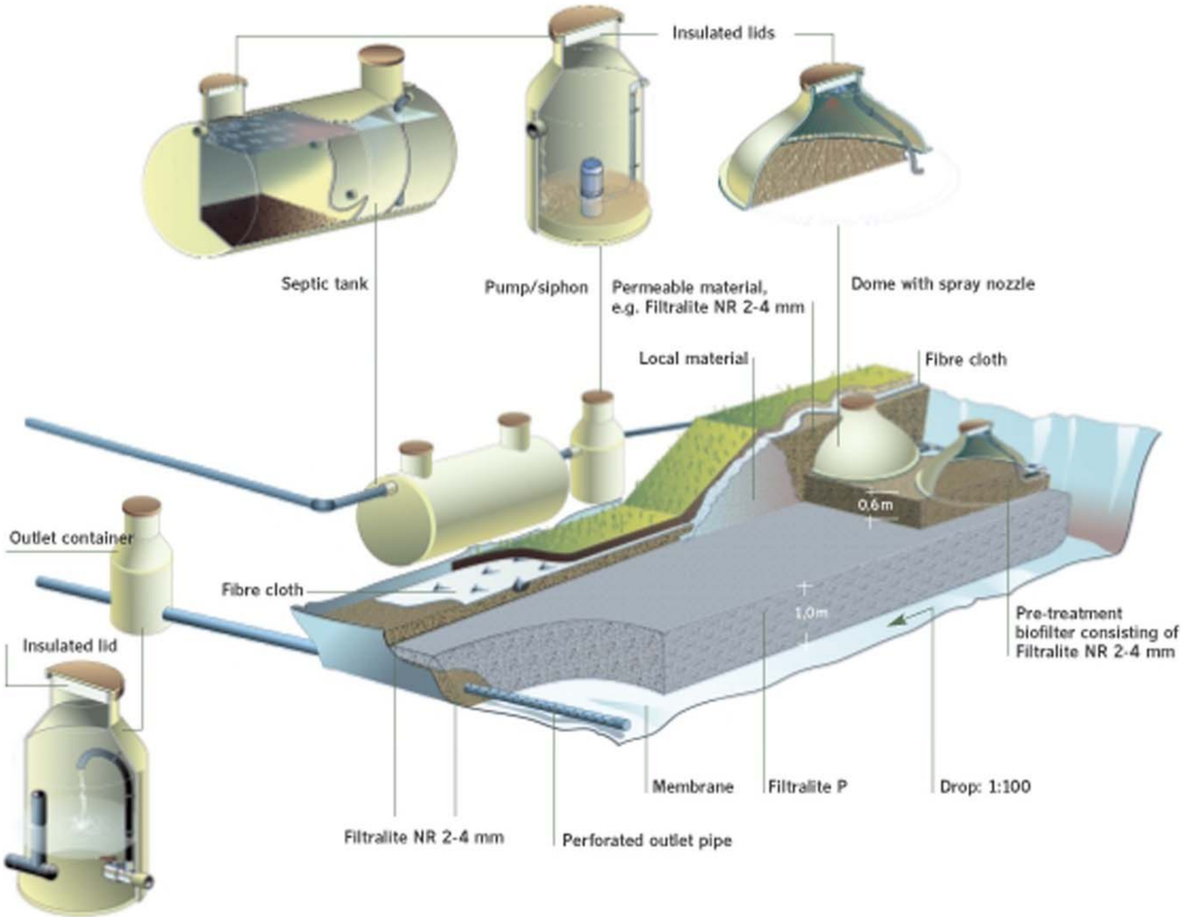


Figure 1 Wastewater treatment system with pre filter and filter bed with different qualities of Filtralite

Table 1 Design of the pilot plants

	DK 1 Denmark	DK 2 Denmark	Pilot 1 Finland	Pilot 2 Finland	Talby Sweden	Fågelsta Sweden	Hvidtsten Norway	Norderås c Norway	Norderås w Norway
	One house	Two houses[1]	One house	Two appartm.	Office + appartm.	Two houses	Two houses	4 appartm.[2]	4 appartm.[2]
Design	5 pe	5 pe	5 pe	10 pe	7 pe	10 pe	10 pe	5 pe	5 pe
Load (l/d)	~ 850	~ 480	100/440/220	1100	370 (140)	468 (360)	~ 500	375/400/750	750/0/288
Septic tank (m^3)	2	2	4	4	6	6	7	7 [3]	7 [3]
Pre filter in	Tanks	Tanks	Domes	Tanks	Tanks	Tanks	Tanks	Domes	Domes
Filtralite quality in pre filters	NR 2 - 4	NR 2 – 4	NC 3 - 8	NC 3 - 8	NR 2 – 4	NR 2 – 4	NC 4 - 10	NR 2 – 4	NR 2 - 4
Surface area (m^2) of pre filters	6,5	6,5	6,3	9 [4]	6,9	6,9	14	3,2 [4]	3,2
Filter bed volume (m^3)	40	40	40	10 (5+5) [5]	50	70	40	7 [5]	23
Filter material in filter beds	Filtralite P 0-4mm	Filtralite P 0-4mm	Filtralite P 0-4mm	Filtralite P 0,5-4mm [6]	Filtralite P 0-4mm	Filtralite P 0-4mm	Filtralite P 0-4mm	Filtralite P 0-4mm	Filtralite P 0-4mm

[1] Two persons in each house
[2] Maximum 9 persons have lived in the house in the period of this investigation, one period with only 2 persons
[3] The two pilot plants at Norderås shares one 7 m^3 septic tank
[4] Pre filter with recirculation
[5] Filter bed is made compact, the filter material is filled in tank(s)
[6] The filter material was changed summer 2004 from Filtralite P 0 – 4 mm to Filtralite P 0,5 – 4 mm, due to hydraulic problems.

1.1 Function of the pilot plants

In the **septic tank** larger particles and some organic matter are removed. The size of the tank and the design will decide how efficient the removal is. After the septic tank the water runs to the **pump well**. The pump in the well could start controlled by a timer or by water level. It is important that the water is equally distributed over the pre filter surface and it is preferable if the water can be dosed equally over day and night.
The **pre filter** is built in domes or tanks, and consists of a down flow aerobic filter with Filtralite NR (NR= normal density, round material) 2 – 4 mm in a 60 cm thick layer. The area of the filter is about 7 m^2 for a one-house plant.
This stage in the treatment process removes most of the organic matter and some nitrification will take place. The load of organic matter on the pre filter will decide the level of nitrification. Two pilot plants were built with recirculation over the pre filter to make the pre filter smaller.

After the pre filter the water runs to the submerged **filter bed** with horizontal flow, 40 m^2 area and 1 meter depth for a one-house plant, filled with Filtralite P. The retention time in the filter beds is about 14 to 21 days, depending of the water consumption in the connected house. Two of the pilot plants are built as compact plants with a compact filter bed, only one fifth of the normal size.
The outlet is in the bottom in the end of the filter bed, and the level of the outlet pipeline inside the **outlet well** is deciding the water level in the filter bed. A two-chamber outlet well can also be used, where the inner section has an overflow, deciding the level in the filter bed, to the next chamber.

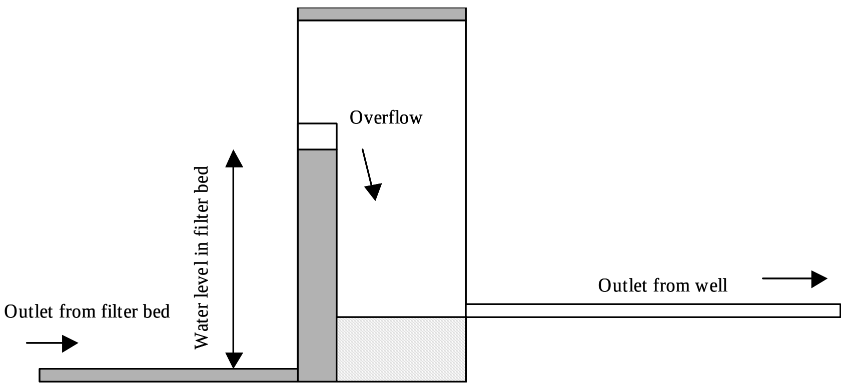


Figure 2 Outlet well with overflow

2.0 Building experiences

The pilot plants in Sweden, Finland and Demark are designed by HACO as, (Norway).
The building of the pilot plants in each country were taken care of by the sub project managers under supervision of Nils Erik Pedersen from HACO.
The pilot plants in Norway are designed and built of the sub project managers, Jordforsk and UMB.

No greater difficulties arose during the time of building of the plants. It was necessary to be thorough and follow the drawings with great accuracy. It was also necessary to be careful not to puncture the tarpaulins during the digging.

The excavation and transport of excavated material became rather extensive due to the local conditions. Everything functioned technically well but the demand for accuracy in the performance of all the work with excavation is great. All bottoms of hollows should be compacted with a vibrator. The filter material was delivered in big bags, which was a simple and well functioning system to handle relatively large volumes of material.

Insulation is important; Filtralite was used for insulation of the filters. The lids of the pump well, pre filters domes and outlet well were insulated with expanded polystyrene. Heating cables were used on the pipe lines from the pump well to the pre filters to prevent freezing.

3.0 Operating Experiences

3.1 Water sampling

Water samples were taken from each pilot plant each month. Samples were taken after the septic tank, after the pre filter and in the outlet well after the filter bed.

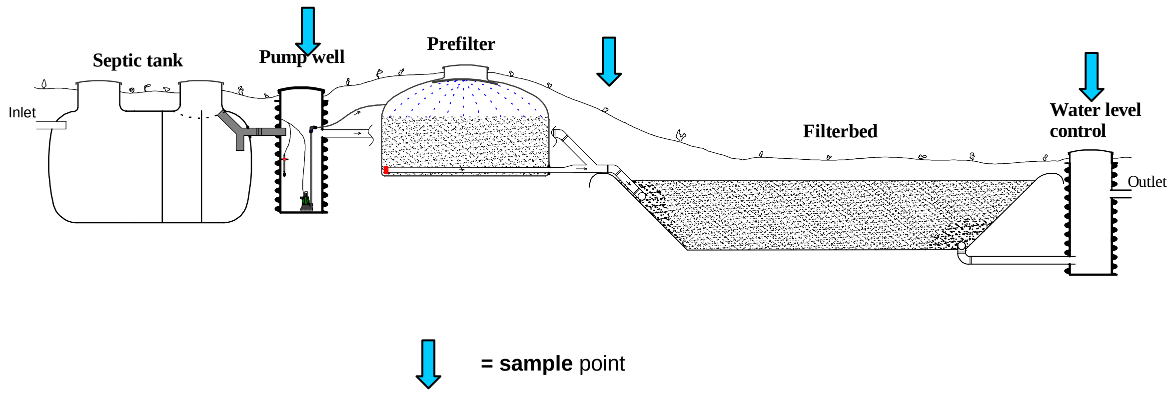


Figure 3 Sampling points (drawing Stockholm Vatten)

3.2 Pump

The pump is the only mechanical equipment in the plant. Only the plants in Denmark have had problems with breakdown of the pumps, probably due to hard water and lime clogging the inside of the pump.

3.3 Pre filter (trickling filter)

3.3.1 Nozzles

The spray nozzles in the pre filter have to be cleaned and flushed. Most particles found in the nozzles were from the building period, some plastic cut off etc. The plants in Denmark have had more problems with clogging of the nozzles, probably due to the hard water.

3.3.2 Surface of the pre filter

The surface of the pre filter should be raked to avoid a too thick biofilm. If there are small water ponds on the surface this should be done more often. One pilot plant in Denmark got coarser Filtralite material on the surface to avoid this.

3.4 Outlet well

Lime will precipitate in the outlet well; the lime is white and can look like stearin at the water surface. The person collection the samples should avoid to get precipitated lime in the water samples taken in the outlet.

At the pilot DK 1 at Mørke in Denmark some of the outlet water was recirculated back to the septic tank to use the lime in the outgoing water for precipitation.

4.0 Results and Discussion

4.1 Load and water flow

The pilot plants have been sampled each month to verify the values on tot P, COD, BOD and nitrogen. All samples are taken as grab samples except for the plants in Sweden where the samples have been a combination of composite samples on week and day and grab samples. Samples are taken after the septic tank, after the pre filter (before the filter bed) and after the filter bed. (See figure 3)

The hydraulic load can vary a lot on plants serving one or two houses. The water flow varies with the activity and the habits to the persons living in the connected house(s). The design parameter for water consumption is given as 110 l/pe d in Finland and 200 l/pe d in Norway. In this project some plants have had a water meter, and the consumption is measured. In other plants the water consumption is assumed. The hydraulic load on each plant is shown in row no 2 in table 1.

There have been some episodes on the water flow into some plants, they are shortly listed below:

- The small wetland at Norderås has been without water for one period, due to only two persons living in the house with four apartments. In this period the water went to the compact plant at Norderås.
- At pilot 1 in Sipoo, Finland, the drinking water well went dry and the water consumption was very low for a long period.
- Pilot DK 2 in Denmark had low hydraulic loads until people moved into both houses connected to the plant.
- The pilot plants in Sweden have had some problems with water leaching into the pipelines /plant. The situations were revealed and corrections made.

4.1.1 Inlet values

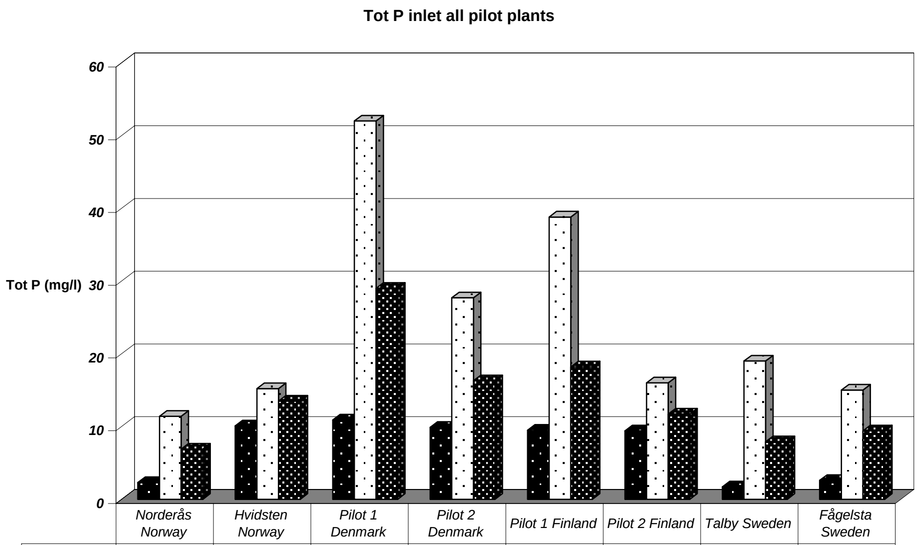
The inlet values used for calculation of treatment efficiency in this project are the outlet of the septic tank. That means that the real inlet values are even higher. The houses connected to the full-scale pilot plants are all family homes except for the pilot Talby in Sweden. The Talby system is connected to an office, which also includes one apartment. The pilot plants

Kuusankoski (Pilot 2) in Finland, Fågelsta in Sweden and Hvidsten in Norway have two houses connected.

As shown in the figures 4, 5 and 6 the composition of the wastewater differs a lot. The phosphorus in the inlet water varies from a level about 10 mg P/l for the Swedish, Norwegian and one of the Finnish plants. The Danish plants and the pilot no 1 in Finland seems to be on a higher level on about 20 mg P/l. This could be due to use of washing machine powder with phosphate, but this is not confirmed. The COD level also varies; it seems that a normal level for COD is 400 to 500 mg/l for family houses. There are also large variations on the nitrogen level in the inlet. The sample with max concentration at pilot plant no 1 in Finland on 270 mg N/l was taken in a period when the houses drinking water well was almost empty and the inlet to the pilot plant was almost as black water (water from the toilet).

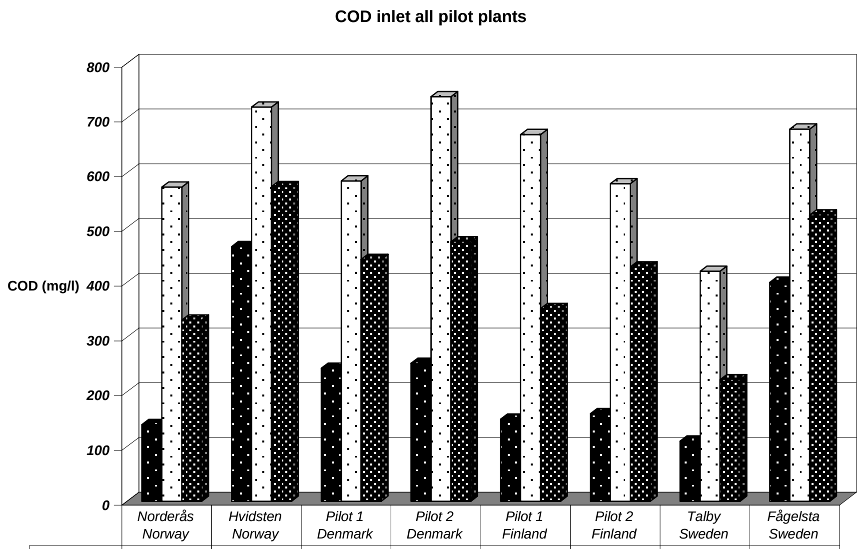
The numbers of samples for each pilot plant varies in this study. Most of the samples are grab samples. For grab samples the day and time the samples have been taken can influence on the results. The water consumption in proportion to the given nutrient loads from the number of persons living in each house (one person is defined to produce each day: BOD_7 = 50 g, tot P = 2.2 g, tot N = 14 g) could also give lower values if the water consumption is high and the values are given in mg of nutrient per litre.

For two pilot plants the water consumption was low in the start-up periods, the inlet values in mg/l for these plants are supposed to decrease when the number of samples increases.



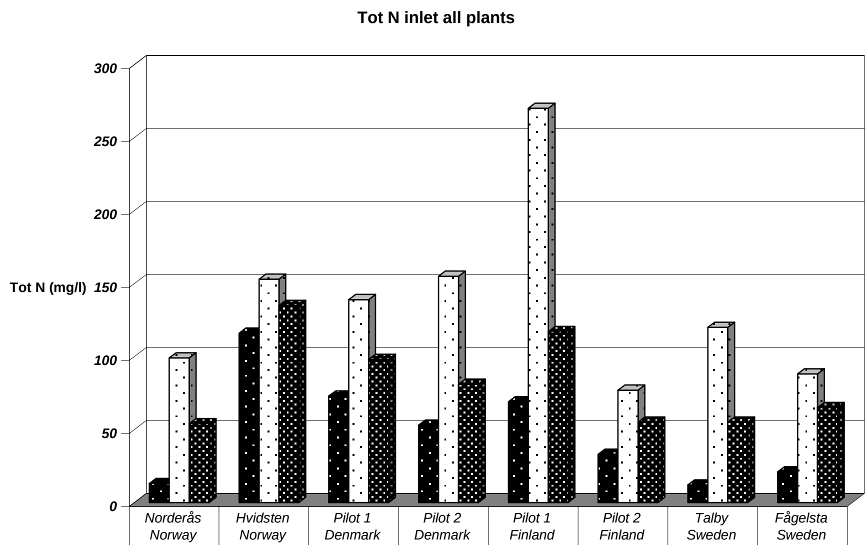
	Norderås Norway	Hvidsten Norway	Pilot 1 Denmark	Pilot 2 Denmark	Pilot 1 Finland	Pilot 2 Finland	Talby Sweden	Fågelsta Sweden
Tot P min	2,3	10,1	10,9	9,9	9,5	9,4	1,7	2,6
Tot P max	11,4	15,2	52	27,7	38,8	16	19	15
Tot P mean	6,9	13,5	29	16,3	18,2	11,7	7,9	9,4

Figure 4 **Min, max and mean values for phosphorus in the inlet water (after the septic tank) to all the pilot plants**



	Norderås Norway	Hvidsten Norway	Pilot 1 Denmark	Pilot 2 Denmark	Pilot 1 Finland	Pilot 2 Finland	Talby Sweden	Fågelsta Sweden
COD min	140	465	243	252	150	160	110	400
COD max	574	720	585	739	670	580	420	680
COD mean	331	575	442	474	352	428	222	523

Figure 5 Min, max and mean values on COD in the inlet water (after the septic tank) to all pilot plants



	Norderås Norway	Hvidsten Norway	Pilot 1 Denmark	Pilot 2 Denmark	Pilot 1 Finland	Pilot 2 Finland	Talby Sweden	Fågelsta Sweden
Tot N min	13	116	73	53	69	33	12	21
Tot N max	99	153	139	155	270	77	120	88
Tot N mean	54	135	98	81	117	55	55	65

Figure 6 Min, max and mean values on Tot N in the inlet water(after the septic tank) to all pilot plants

4.2 Treatment efficiency

Treatment efficiencies for all pilot plants are given in table 2. The average results are 99% for total phosphorus, about 50 % for total nitrogen and about 85 % for COD. The results for organic matter are from a relatively short period and the results from start up periods influence much on the average. Treatment efficiency on 90 % or higher is normally achieved in these systems after the start up period when the biofilm is fully developed.

Table 2 Treatment efficiencies for all pilot plants on phosphorus, total nitrogen, chemical oxygen demand and biochemical oxygen demand (results including start up periods).
[1] average value with start up period, median BOD value for Talby was 83,3 %. (See figure 8 for numbers with and without start up period).

	Tot P % reduction	Tot N % reduction	COD % reduction	BOD % reduction
Norderås compact Norway	98	40	94	96
Norderås small wetl Norway	99	56	92	96
Hvidsten Norway	99	39	82	81
DK 1 Denmark	94	50	90	90
DK 2 Denmark	99	57	90	90
Pilot 1 Finland	99	46	90	95
Pilot 2 Finland	95	46	92	96
Talby Sweden	99	43	73	37 [1]
Fågelsta Sweden	99	66	89	82

4.3 Total Phosphorus

The main removal of phosphorus takes place in the filter bed with Filtralite®P. The pilot plants with full scale filer beds and the small wetland at Norderås (half of full scale) have all 99 % removal of phosphorus in period of the project with exception from the pilot DK 1 in Denmark. This plant has been built with three outlet sections and outlet has not been switch over to the next before the effluent has been decreasing the discharge limits. This plant has also received the highest inlet values of phosphorus.
The compact filter beds (Norderås Compact, Norway, and Pilot 2 in Finland) have both had some problems with the hydraulic conditions, but both plants have average treatment efficiency on 95 % and higher for the period from 2002/2003 to summer 2005.

4.4 Total Nitrogen

Removal of total nitrogen is varying from 39 to 66 %. The total removal of nitrogen depends of the nitrification and the denitrification. The conditions for denitrification are not optimal in these systems; denitrification will mainly take place in the submerged filter bed. The most of the organic matter is removed in the pre filter and the available carbon source is limited. The high pH in the filter bed is not optimal for the denitrification biofilm.

4.4.1 Nitrification

The nitrification process is mainly taking place in the pre filters of the plants. The load of organic matter, oxygen level, temperature and the condition of the biofilm will influence on the nitrification efficiency. The nitrification degree is varying from 33 to 88 %. Three of the plants have pre filters below domes and the others have pre filters in tanks. It seems that the nitrification in filters below domes can be more efficient than in tanks but the loading and the running of the Norderås pilot plants have been very varying witch makes it is too early to conclude.

Table 3 Nitrification, all pilot plants.

		Nitrification		
	Pre filter	Average (%)	Median (%)	Comments
Norderås Norway compact pant, recirculation	Dome	~90		first periode, later 20 - 80 %
Norderås Norway, small wetland	Dome	~70/~75		stabile periodes before Oct 03 and after Sept 04
Hvidsten Norway	Tanks	33		
Pilot 1 Denmark	Tanks	76		pre filter, whole plant 85%
Pilot 2 Denmark, rebuilt to recirucation	Tanks	61		pre filter, whole plant 76%
Pilot 1 Finland	Domes	88	94	
Pilot 2 Finland, compact plant, recirculation	Tanks	68	72	
Talby Sweden	Tanks	75	76	without start up period
Fågelsta Sweden	Tanks	70	77	without start up period

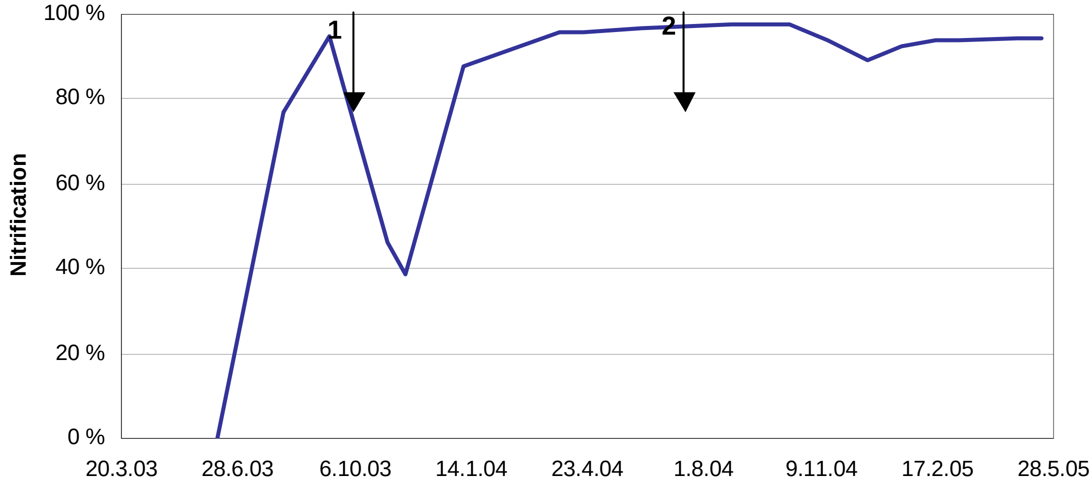


Figure 7 The nitrification of the pilot 1 in Finland with pre filters below domes. 1) new drill well, 2) new family in the house connected. (FEI/SYKE)

4.5 Organic Matter

Organic matter is this systems removed in the septic tank and in the pre filter. This project has not looked in to the removal of organic matter in the septic tanks. Removal of organic matter is very good in the pilot plants. The start up period is the critical part of this process and plants with start up in wither time need some extra months before stable high removal efficiency is established. The results from Stockholm Water's plants Fågelsta and Talby is show in figure 7 BOD_7, COD and TOC including the start up period and expelling the start up period.

The plants with recirculation over the pre filters have a little higher removal efficiency than the rest, but in general all plants perform.

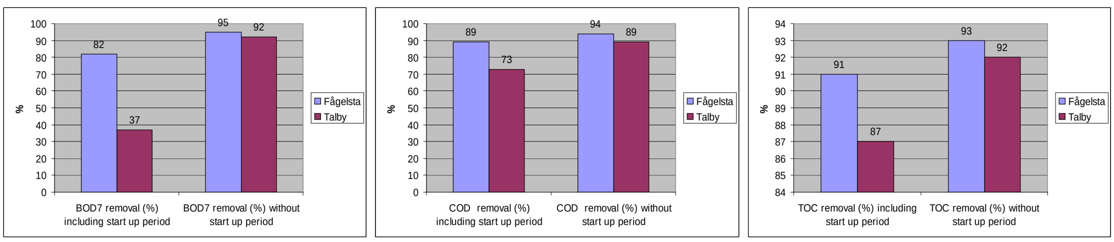


Figure 8 Treatment efficiency on organic matter with and without start up period for Fågelsta and Talby pilot plants, Stockholm Water.

4.6 Bacteria

The tests in Denmark showed 2 log units removal of total coliforms and thermo resistant coliforms after the pre filter. After the filter bed all plants have had 99.9 % removal of bacteria. The high pH in the filter bed will inactivate the bacteria coming with the sewage; this pH effect will decrease with the age of the filter bed.
The compact plant in Kuusankoski (Pilot 2 in Finland) had higher bacteria levels, variation from 10 to more than 300 cfu/100 ml. The higher amounts were detected mostly in context with the increased phosphorus concentration in the effluent.

5.0 Regulations

5.1 Treatment requirements

The requirements on wastewater treatment in rural areas vary in the Nordic countries. Below are the statuses concerning rules for each Nordic country presented:

5.1.1 Iceland

So far Iceland is the only country without requirements for rural areas, but with more cabin and cottage settlement in the inland the need for treatment of wastewater will arise also here.

5.1.2 Sweden

On the national level, there is a general demand that wastewater should be managed in order to minimise hygienic risks and to avoid negative environmental impact. The use of non-renewable resources shall be as low as possible and valuable resources (such as phosphorus) shall be recovered. Earlier, the regulation concerning small onsite treatment systems was mainly focused on health aspects and it was required that septic tank effluent should be treated before discharge to the recipient. The interpretation of this regulation was given by Swedish Environmental Protection Agency (SEPA) who suggested an infiltration bed or a filter bed after the septic tank (SEPA, 1987). Today, there is no official guideline available for small onsite wastewater treatment plants from SEPA. However, new regulations, with demands for nutrient removal etc. are expected in December 2005.

In this project, we were aiming at the requirements from another project in Sweden, “Bra Små Avlopp”, that consisted of plants in the size of 5 pe (Hellström et al., 2003). The required degree of removal of phosphorus, nitrogen, and BOD_7 in that project is given in table 4, and it was used in this project as a goal.

Table 4 The goals for the removal efficiency in the project “Bra Små Avlopp”.

	Minimum removal efficiency	Desirable removal efficiency
Phosphorus	> 70 %	> 90 %
Total nitrogen		> 50 %
Ammonia nitrogen		> 90 %
BOD_7	> 70 %	> 90 %

5.1.3 Finland

The revised environmental protection and water legislation came into force in Finland on 1 March 2000. The Environmental Protection Act (86/2000) implements the European Union directive on Integrated Pollution Prevention and Control (IPPC), which obliges EU member states to integrate the control of emissions caused by industry. According to the Environmental Protection Act, wastewater from areas that are not connected to sewer networks must be effectively drained and treated to ensure that there is no risk of pollution. According to the act the national objectives are that the BOD load and phosphorus load would diminish 60 % and 30 % respectively, compared to the situation in the beginning of 1990's.

The Government Decree on Treating Domestic Wastewater in Areas Outside Sewer Networks (542/2003) entered into force 1.1.2004. It sets minimum requirements for the construction and operation of wastewater systems and treatment processes. The Decree covers all new wastewater systems immediately. For the old ones transitional period for implementation is 10 years. Wastewater systems built before 2004 must fulfill the general treatment requirements of the decree before 1.1.2014 instead of exceptions provided on case-by-case basis.

All systems must have a wastewater system report which fulfils certain requirements. For existing systems with or without WC-wastewater, system report has to be done before 1.1.2006 or before 1.1.2008, respectively.

Communities can give treatment requirements in municipal environmental protection regulations. Depending on the local circumstances the municipal requirements can be tighter or lighter than the general treatment requirements of the degree. However local requirements must always be equal or tighter than the values given in last two columns in table 5 (local requirements). General and local treatment requirements of the degree are presented in table 6.

Table 5 Treatment requirements according to the Government Decree on Treating Domestic Wastewater in Areas Outside Sewer Networks.

Parameter	Normal load of untreated wastewater (g/person/d)	GENERAL REQUIREMENTS		LOCAL REQUIREMENTS	
		Required reduction (%)	Permissible load of treated wastewater (g/person/d)	Required reduction (%)	Permissible load of treated wastewater (g/person/d)
BOD_7	50	90	5	80	10
Tot-P	2,2	85	0,33	75	0,66
Tot-N	14	40	8,4	30	9,8

In Table 20 the maximum concentration of BOD_7, total phosphorus and total nitrogen are calculated with the water consumption of 110 litres per capita per day.

Table 6 Maximum permissible concentrations of wastewater with the water consumption of 110 litres per capita per day according to the Government Decree on Treating Domestic Wastewater in Areas Outside Sewer Networks.

Parameter	Normal concentration of untreated wastewater (mg/l)	GENERAL REQUIREMENTS		LOCAL REQUIREMENTS	
		Required reduction (%)	Permissible concentration of treated wastewater (mg/l)	Required reduction (%)	Permissible concentration of treated wastewater (mg/l)
BOD_7	455	90	45	80	91
Tot-P	20	85	3	75	6
Tot-N	127	40	76	30	89

5.1.4 Denmark

The removal demand for these kinds of systems in Denmark will depend on the location of the system and the sensitivity of the receiving environment. In general, the discharge demands will simultaneously limit the discharge concentration and demand a specific percentage removal of organic matter, the nitrification of the influent and the removal of phosphorus respectively. For organic matter the strictest regulation demands the removal of 95 % of the incoming BOD_5, a discharge concentration no higher than 10 mg L^{-1}. The restriction for nitrification demands that 90% of the influent should be nitrified and the discharge can not be higher than 5 mg L^{-1} $NH_3 + NH_4$-N. For P, the removal must reach 90% of the influent total P, while the discharge concentration can not exceed 1,5 mg L^{-1}.

5.1.5 Norway

The new regulations for this type of treatment plants in Norway are based on " Forskrift om utslipp fra mindre avløpsanlegg", report no 1741/2000 SFT. This regulations transfer the authority for these smaller plants to the local municipality. The new regulation makes it possible that each municipality makes their own guidelines. Therefore these rules vary from place to place.

Some community's demands that the water discharged shall have bathing water quality in the outlet with respect to the indicator bacteria concentration. This means less than 1000 TKB/ 100 ml. Other municipalities demand a phosphorus discharge limit at 1.5 mg P /l and other says 1.0 mg P/l as maximum. Some few counties also demand maximum limits for organic and suspended solids.

5.2 Requirements on reuse of saturated filter material

When the Filtralite P material has been saturated with phosphorus it has to be changed with new, fresh material. Used material should be reused as a soil improvement on agricultural land. MTT (Finland) has made a thorough study on the reuse of phosphorus from saturated Filtralite P material. More info in the report **"Wastewater treatment in filter beds: reuse of filter material"** by Anna Mari Nyholm, Markku Yli-Halla and Pekka Kivistö (MTT).

Reused material should not contain heavy metals or bacteria concentration above certain limits. UMB (Norway) has made a study on the heavy metal and bacteria content in filter material from five different filter beds in Norway. The report **"Heavy metals accumulation and hygienic indication in subsurface flow constructed wetlands"** by Adam M. Parauch, Tore Krogstad, Petter D. Jenssen and Gunnar Stensen (UMB) gives more info in this subject.

The regulation concerning use of the phosphorus saturated filter material is not quite clear. There is however no indication today that use of filter material in agriculture will be prohibited as long as the quality requirements for sewage sludge are fulfilled. Further work on making more clarified and simple directions for reuse is planned in an extension of this project.

6.0 Nordic Design Guideline

One of the main goals in the project was to make common guideline for this type of wastewater treatment plants for the Nordic Countries. The guideline is in appendix 3 and based on the Norwegian guideline "VA miljøblad no 49 Våtmarks filter" and the experiences achieved in this project. An overview and some ideas and discussions about how to improve the system further are summarized in this chapter.

6.1 Septic tanks

The national regulation on the size of the septic tanks for one house varies from 2 m^3 in Denmark and Finland to 4 m^3 in Norway. There are also variations between the Nordic countries on how often the septic tanks should be emptied. A poor functioning septic tank will in any case increase the load of organic matter on the pre filter and at worst case clog the pre filter.

6.2 Pre filters (trickling filters)

The pre filter is the main process step for reduction of organic matter and nitrification of ammonium to nitrate. The surface area of the filter is dimensioning and the pre filter should not be built to small. If the space is limited, one way to get the pre filter smaller is to recirculate the water over the pre filter. Recirculation is easies if the pre filter is in tanks. An extra pipeline back to the pump well, some extra valves for regulation in the pump well and a pump well with two chambers are needed.

6.2.1 Improvement of nitrification

Tests done in Finland, show that the oxygen demand in the pre filters is higher than what is available. Better aeration of the pre filters could give higher nitrification rates. This could be done with passive or active aeration of the deepest section of the pre filter.

6.2.2 Improvement of denitrification

Denitrification takes places in the filter bed. This process needs a carbon source and anoxic conditions. One way to increase the C/N ration could be to recirculate the outlet water from the pre filter to the septic tank and use the organic matter in the inlet water as carbon source.

6.3 Filter beds

The design of the filter bed was originally decided by retention time, 14 days retention time was the minimum. With the pre filter in front of the filter bed and the new Filtralite P material in the filter bed the hydraulic conductivity and the lifetime of the filter material has been dimensioning for the filter bed. The Filtralite P material used in the filter beds is so efficient that the filter bed can be made smaller or put in a large tank. Then the material has to be replaced more frequently, but the need of space is less. The inlet values of phosphorus should be evaluated when designing the size of the filter bed.

6.3.1 Inlet and outlet zones of the filter bed

The hydraulics in the different filter beds is not investigated in this project. The plants with pre filters in domes have the inlet flow from the pre filter directly down to top of the filter bed, while the plants with the pre filters in tanks have the inlet flow from the pre filters in the bottom of the filter bed. The outlet of the filter bed is in the opposite end and in the bottom of the bed. The figure 7 tries to illustrate the flow patterns for these different solutions.

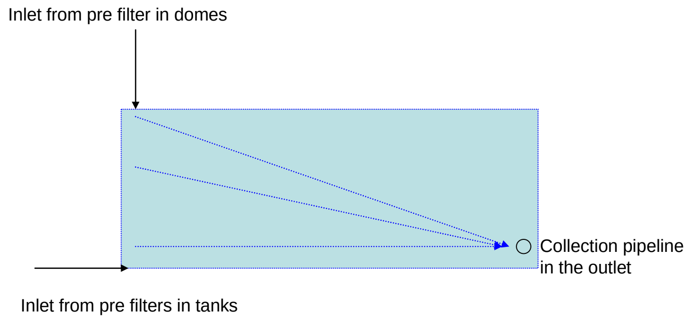


Figure 9 Flow patterns in the filter beds system with alternative 1) inlet on the top from domes and alterative 2) in the bottom from tanks and today's outlet system

A way to get the flow more equally distributed in the filter bed could be to make an outlet collection section of coarse material in the whole depth of the bed.
The thought flow pattern for the two solutions is shown in figure 10 and 11.

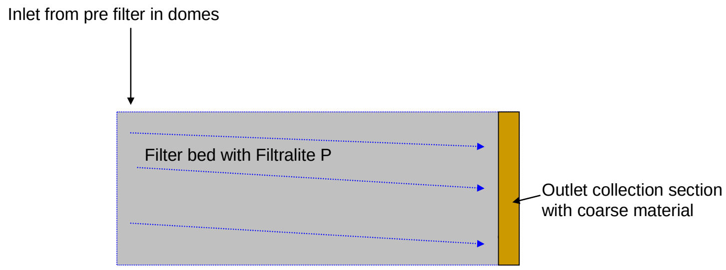


Figure 10 Possible flow pattern with coarse outlet section with pre filter on top of the filter bed

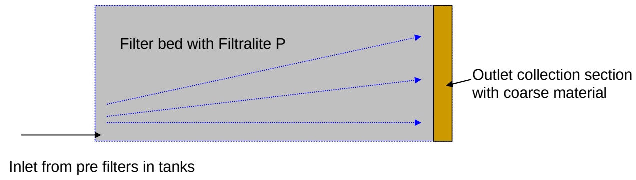


Figure 11 Possible flow pattern with coarse outlet section with inlet from pre filter in the bottom of the filter bed

6.3.2 Size of the filter bed

The filter bed designed after the Norwegian VA miljøblad no 49 is rather large, 40 m^3 for one house (5 pe). It could be possible to make the filter bed smaller and to change the Filtralite P material more often.
The filter bed at Norderås (Norway) is made 58 % of a normal filter bed. This plant has been without water for one period, due to few persons living in the house.

The compact plant at Norderås has a filter bed in one tank, 7 m^3, with up-stream water flow. The filter bed ran well until the distributions pipeline in the bottom clogged, spring 2005.

The plant in Kuusankoski (Finland) is built with two compact filter beds in series, each on 5 m^3. The flow was in the beginning up-stream in both tanks, but due to clogging etc the flow was changed to down stream in October 2004. The material in these tanks was changed from Filtralite P 0 – 4 mm to Filtralite P 0.5 – 4 mm summer 2004 due to hydraulic problems in this step of the plant. The Filtralite®P 0.5 – 4 mm has a lower phosphorus binding capacity than ordinary Filtralite®P but higher hydraulic conductivity.

The compact filter beds have had good treatment results in long periods when the hydraulic parts functioned correctly.

7.0 Conclusion

The filter bed system with pre filter has shown stable outlet values for phosphorus and nitrogen, as well as for organic matter. The system has no problems with peak loads.
To maintain the high treatment efficiency the septic tank should be emptied regularly and the filter material in the filter bed has to be changed when saturated and/or the phosphorus concentration reaches the discharge limit. Estimated lifetime is 15 years for a 40 m^3 bed with inlet values about 10 mg P/l. Normal maintenance of the inlet pump in the pump well and nozzles in the pre filter is also necessary.

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Pictures from the pilot plants

Finland

Pilot no 1 in Sipoo

Pilot no 2 in Kuusankoski

Sweden

Talby

 

Fågelsta

 

Denmark

DK1 Mørke


DK2 Friland


Norway

Hvitsten

Norderås

Nordic Design Guideline for Filter Bed with Pre Filter

Aim

The aim with this guideline is to give advice for design and building of small wastewater treatment plants of the type filter beds with pre filter. The advice is based on the experience achieved in the project "Wastewater treatment in filter beds" run by support from NICe in the period 2002 – 2005. The design criteria are given for from one house up to four houses (the dimensioning number of persons in one house is five). The basis could be used for design of larger plants up to 100 pe.

Introduction

Filter bed with pre filter is a three step treatment plant with the following steps:

- septic tank with sedimentation of particles
- biological pre filter (trickling filter) with removal of organic matter and nitrification
- filter bed with phosphorus removal, denitrification and removal of pathogenic organisms

Table 1 Normal treatment efficiency for filter beds with pre filter

Parameters	% Removal	Typical discharge concentrations
Total phosphorus	> 90%	< 1 mg l^{-1}
Organic matter (BOD_7)	90%	< 20 mg l^{-1}
Total nitrogen	40 - 60 %	
Nitrification	50 – 90 %	
Thermo tolerant bacteria	> 99.9 %	< 1000 TCB/100ml

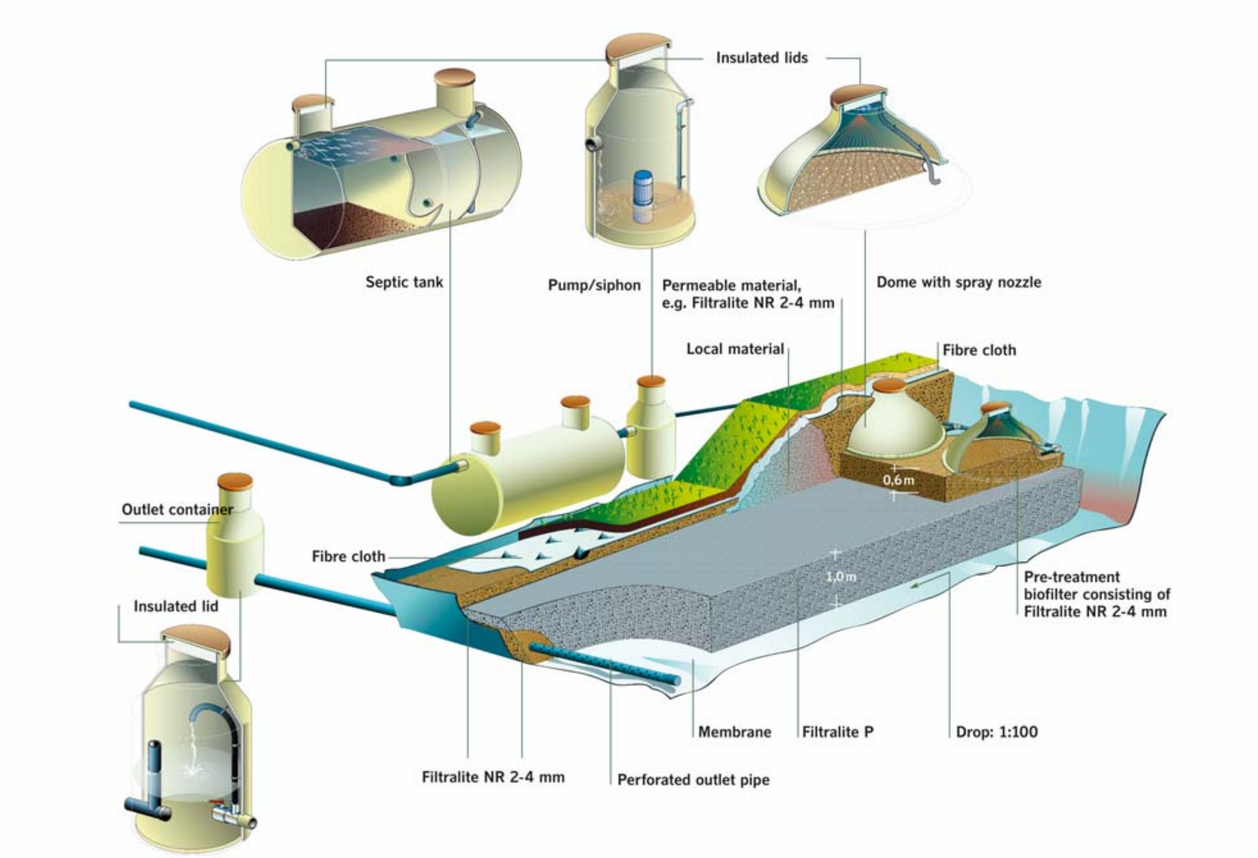

Figure 1 **Filter bed with pre filter**

Septic tank

The septic tank should be constructed with three chambers. The national regulations on the size of the septic tank are followed; the regulations on volume vary from 2 m^3 in Denmark and Finland, 4 m^3 in Norway and Sweden has 3 m^3 as standard for one house. Existing septic tank should be inspected and evaluated before connected to a new treatment plant; if the conditions are unsatisfactory it must be changed.

Regular emptying of the septic tank is important. A poor functioning septic tank will increase the organic load on the pre filter and in worst case clog the pre filter.

Other pre treatment solution can be used if that gives the same treatment efficiency on particles as a three chambered septic tank.

Pump well

The pump well works as a small retention basin. The pump in the well could start controlled by a timer or by water level. It is important to dose the wastewater in small quantities to the pre filter. If controlled by the water level, the level between start and stop signal to the pump should not be too large; the dose should be less than 50 litres. For larger plants the dose should be controlled on time and average 24 to 48 doses per day could be used.

Pre filter (trickling filter/ biofilter)

The main organic removal is performed by the biofilm in the pre filters. The filter surface area is the dimensioning parameter and a minimum surface is needed.
The minimum surface area is given in table 2.

The pre filter is in practice a low loaded aerobic trickling filter. There is no backwashing of the pre filter. The outlet wastewater from the septic tank is dosed over the filter surface by the nozzles in the ceiling of the domes or tanks. It is important that the nozzles spray the water equally over the whole surface of the filter. Biofilm is established on the Filtralite® aggregates some weeks after start up. Start up in winter time will take longer before the optimal biofilm is established than start up in summer time.

The pre filter consists of a 60 cm thick layer of Filtralite® NR 2-4 mm or similar material. More coarse material could be used on the top layer, i.e. Filtralite® NR 4-10 in the upper 10-20 cm, to avoid clogging and formation of small ponds on the top of the pre filter.

Two or more domes are placed above the pre filter and serves as a hemispherical cover. The domes shown in the figure 1 have a diameter of approx. 2.0 meters. Two nozzles in each dome enable wastewater to be sprayed over the filter surface. The nozzles ensure that the water is sprayed evenly and that maximum usage is made of the filtration material. The wastewater runs vertically through the filter.

The pre filter may be placed over the filter bed or separately. The pre filter shown in figure 1 is placed over the filter bed. A description on how to clean the nozzles is given in Appendix 4 “Users Manual - Filter Bed with Pre Filter”.

The oxygen level in the pre filter affects the nitrification efficiency. Higher nitrification could be achieved by more effective aeration of the pre filters. Pre filters could be built in tanks or below domes. In the project the nitrification level has been better in the pre filter with domes than in tanks, but also here the dissolved oxygen level was below the optimal for nitrification.

Table 2 Minimum surface area of the biofilters

No. of houses	Biofilter no. of domes[1]	Minimum surface area (m^2)
1	2	6
2	3	9
3	4	12
4	5	15

The pre filter could be built with recirculation to make the dimensions of the pre filter smaller and/or make the treatment efficiency better. Experience has not show better nitrification with recirculation, probably due to limiting aeration of the filter.

Filter bed

The main purpose of the filter bed is to remove phosphorus from the wastewater. This occurs as the phosphorus react with the Filtralite®P material. The actual filter bed is an excavated basin filled with Filtralite®P with a depth of approx. 1.0 meter. The bottom of the filter bed is built with a slight slope at the bottom (1:100). At the point where the pre filter is positioned above the filter bed, the water runs vertically through the pre filter and down into the underlying submerged basin containing Filtralite®P. If the pre filter is placed in a separately location, a transmission pipe from the pre filter to the filter bed and a distribution channel with coarse media and distribution pipe in the inlet zone is needed.

Filter bed design figures are given in table 3 for from one up to four houses with designed water consumption of 200 l/person and day and slope at the bottom at 1:100. The dimensioning number of persons in one house is five.

Table 3 Design of the filter bed, with water consumption 200 l/ person and day, i = 1:100

No. of houses	Amount of Filtralite® P (m^3)	Minimum width B (m)	Length L (m)
1	40	4,5	9
2	70	8	9
3	100	11,5	9
4	130	15	9

The dimensions of the filter bed are determined by the hydraulic conductivity of the filter material and by Darcy's law:

$$Q = K*W*D*i$$

[1] The diameter of each dome is approximately 2.0 meters. (Domes or tanks with other diameter could be used but the total surface area should not be below the minimums given in table 2).

Q = Hydraulic capacity (m^3/h)
K = Hydraulic conductivity of the filter material (m/d)
W = Width of the filter bed (m)
D = Depth of the filter bed (m)
i = Hydraulic gradient between the inlet and outlet

The retention time in the filter bed should be a minimum 10 days for municipal wastewater. The length of the filter bed is given by the equation:

$L = V_{water}/ D*W$

V_{water} = Storage capacity for water in the filter bed (m^3) [2]
D = Depth of the filter bed (m)
W = Width of the filter bed (m)

To get more square filter beds, the hydraulic gradient could be changed to 1:50. This gives the numbers in table 4.

Table 4 Design of filter bed, with water consumtion 200 l/ person and day, i = 1: 50

No. of houses	Amount of Filtralite® P (m^3)	Minimum width B (m)	Length L (m)
1	40	6	6.7
2	70	8	9
3	100	8.5	12
4	130	11	12

The bottom and the walls of the filter bed must be watertight and should be covered by a water proof membrane. Geo-textile should be used to protect the membrane. Geo-textile should also be put on the top of the filter bed to prevent soil to mix with the Filtralite®P material.

The Filtralite®P material in the filter bed will slowly be saturated with phosphorus and after a number of years the outlet water will reach the discharge limit given by the authorities. How fast the filter will be saturated depends on the loading of phosphorus to the plant, if the loading is high the life time of the filter material will be shorter. When the filter material is saturated with phosphorus it must be replaced with new fresh material.

The average capacity for Filtralite®P is given to 3 g P / kg material.

[2] Given from the desired retention time and the voids (or effective porosity reduced with 25 %) of the filter material.

Outlet well

The outlet from the filter bed is piped through an outlet well. The outlet well could be built with a flexible pipeline or with an inner well with an overflow; the height of the pipeline or the overflow is controlling the water level in the filter bed. By lowering the water level in the outlet well the filter bed is emptied for water which can be needed for maintenance work.

Samples of the effluent could be taken in the outlet well.

The water can be discharged into a river, a lake or be infiltrated into the ground. The infiltration ditch should be made of permeable material as Filtralite®NR 10 – 20 mm and with enough storage volume for precipitation of surplus lime. The ditch should be possible to flush with water and pipes for this should be prepared.

pH in the outlet water

The pH in the effluent from directly new started plants is approximately 12.7, depending on the design of the plant and the water to be treated. In cases where the recipient requires lower pH, this can be accomplished by dilution or aeration. More information is given in appendix 5 “Dilution and aeration of effluent from onsite wastewater treatment systems using Filtralite P”.

Insulation

The Nordic countries have areas with cold climate in winter time and insulation is required. All the lids on all tanks, domes and wells should be insulated with expanded polystyrene and heating cables should be used on the pipelines from the pump well to the pre filters.
The top of the filter bed should be insulated with 10 – 20 cm Filtralite®NR 10 - 20 or similar.

Operation and maintenance

The operation of the pump is very important, if the pump fail the pre filters will be out of operation. Appendix 4 “Users Manual - Filter Bed with Pre Filter” gives an overview of the maintenance needed for this treatment plants. The authorities decide if the owner should have a maintenance agreement with a company specialised on maintenance of this type of wastewater treatment plants.

On behalf of the project group:

Oslo 24.10 2005

Magnhild Føllesdal
Project Manager

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Reference list:

Norwegian "VA miljøblad No 49, 2001 Våtmarksfiltre (filter beds)" from the foundation NKF and NORVAR.
Report from the pilot plants in Finland, Riikka Vilpas (SYKE),Matti Valve (SYKE), Satu Räty (maxit Oy)
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Wastewater Treatment in Filter Beds, **Report from pilot plant Hvitsten, Norway**, Trond Mæhlum and Jens Chr. Køhler (Jordforsk)
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Wastewater Treatment in Filter Beds, Results from the pilot plant DK1 at Mørke, Denmark, Carlos A.Arias and Hans Brix (University of Aarhus)
Wastewater Treatment in Filter Beds, Results from the pilot plant DK2 at Friland, Denmark, Carlos A.Arias and Hans Brix (University of Aarhus)
Common Report from all the Pilot Plants, Magnhild Føllesdal (maxit Group)

USERS MANUAL - FILTER BED WITH PREFILTER

OCCUPIERS USE OF THE WC

The householder shall not throw waste in the toilet.
Following things shall not be thrown in the toilet:

- Q-tips
- Paint
- Paint remover
- Oil
- White spirit
- Rags
- Wet serviettes

SEPTIC TANK

The septic tank has to be emptied regularly. The sludge level in the first chamber should be sounded/ measured. If the sludge layer is higher than 10 cm beneath the bushing to the next chamber, the septic tank has to be emptied.
Control the inlet; it should not be blocked.
The submerged outlet pipe must also be controlled.

It is very important for the efficiency of the treatment plant that the septic tank is well functioning.

THE PUMP and THE PUMPWELL

The pump

The light on the control lamp should be controlled once a week.
If the light is red, you have to check the pump after the following list:

If the pump stops:

1) Control the electricity
2) Control the float switch which gives the level for start and stop of the pump

If nothing of this works, the pump has to be taken up of the well.

The pump could be dirty of sludge, so if needed wash the pump. It is important that the float switch is clean so it can move freely up and down in the pump well.
It is recommended to loosen the rapid coupling and take the pump up of the well and wash it outside of the well.
If the pump stops and both the electricity and the float switch are ok, the pump has to be taken up of the well. Something can be clogging the pump inside or the pump can be destroyed.

- If there is sludge on the pump, the pump has to be washed.
- Try to move the impeller and loosen it, particles etc. clogging it should be carefully removed. Remember to unplug the electricity!

It is important that the float switch is clean so it can move freely in the pump well.

Control the free length of the float switch. This should be about 10 cm. If it is too short it can prevent the pump to start.
Too long length gives a large quantity of water at once to the pre filter, which is not good.
Install the pump in the pump well and connect the pipeline on the rapid coupling. Please note that when installing the pipeline the flexible tube has to be connected on the inside of the O-ring in the coupling.

PRE FILTER

Nozzles

There are two nozzles in each pre filter dome. Grease and particles can clog the nozzles and reduce the water flow. If the nozzles are clogged, loosen them from the pipe and flush them with clean water and soap or try to pick them open. Put the nozzles back, start the pump and adjust the disperse zone. The whole surface of the pre filter should get wet and the water should be distributed evenly on the filter surface.

Filter surface

The filter surface could be covered with a thick bio-film and the surface should then be raked twice a year. If there are problems with small water ponds on the surface of the pre filter this should be done even more often. It is important with good air access down in the pre filter.

FILTER BED

The pipes for washing the pipeline have to be closed carefully. If necessary mark the pipes so it is easy to find them in the terrain. There should not be any water on the top of the filter bed, if it is the outlet pipe or well is clogged. Clean the outlet well. If the outlet pipeline is clogged, the pipes have to be used for jet water washing.

The authorities decide how often samples should be taken of the effluent. The discharge limit will decide when the filter material has to be changed. Expected lifetime for the Filtralite P material is 15 to 20 years. Used material has to be dug out and could be used as soil improvement on agricultural land after agreed application to the authorities. New Filtralite P material can be ordered from *maxit*.

OUTLET WELL

If the outlet pipeline from the outlet well is clogged with lime, remove the lime.
This could be a problem in the start-up period.
The outlet well has two chambers to ensure to hold back rests of lime from the filter material.
If needed the outlet well has to be emptied for lime sludge with a septic truck.
The water samples should be taken in the last (second) chamber and in the middle of the water surface to ensure a representative water sample.

TROUBLE SHOOTING

Alarm:
Control the float switch of the pump. Is it possible for this to move freely?
If not try to move the pump a little bit.
If necessary wash the float switch clean.
Control if the pipeline from the pump to the pre filters is frozen or clogged.
Control if the nozzles are open. If necessary loosen the nozzles and wash them in soap water.

High water level:
In the septic tank:

- Control the inlet and outlet in the septic tank. If necessary, empty the septic tank sludge.

In the filter bed:

- Remove lime sludge in the outlet well. Chamber one is important.
- If the outlet pipeline is clogged - Jet water washing can be necessary.

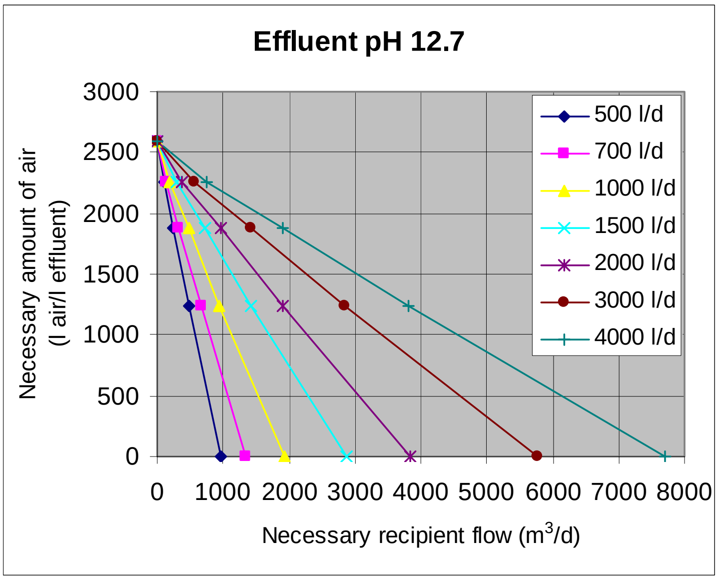
Dilution and aeration of effluent from onsite wastewater treatment systems using Filtralite P

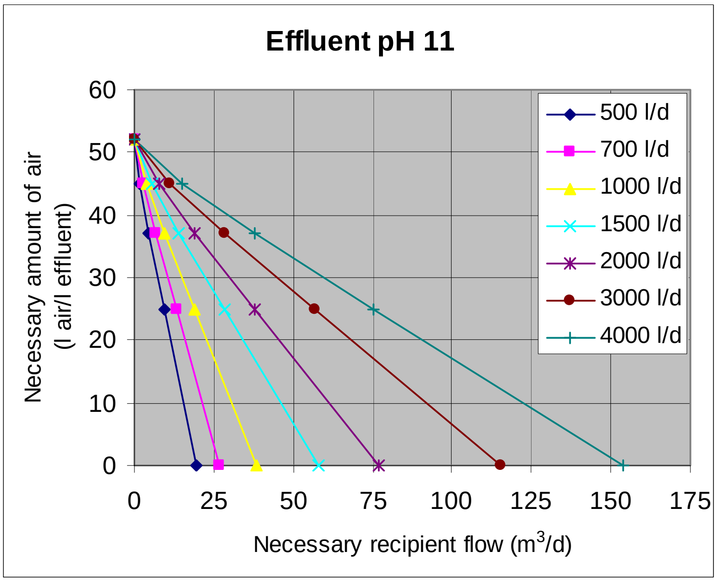
Onsite wastewater treatment systems using Filtralite P are optimised for the removal of phosphorous.

The effluent pH from these systems is relatively high, especially in the start-up period. In cases where the recipient requires a lower pH, this can be accomplished by dilution or aeration. This is a good solution in areas of small and sensitive recipients.

The figures below are based on real values from two different effluents. The water with a pH of 12.7 represents the effluent directly after start-up of the plant, and the effluent with a pH of 11 represents a plant after some months of operation. These values will vary from one plant to another dependent on the design and operation of the plant. The figures show how much water that is needed for dilution (i.e. required flow in the receiving river) and how much air that is needed, or combinations of the two, to reduce the pH.

The calculations are based on the assumptions that the dilution water has a pH of 6.5, a temperature of 10 ºC, and that the pH in the receiving river shall not exceed 8.5 after mixture.





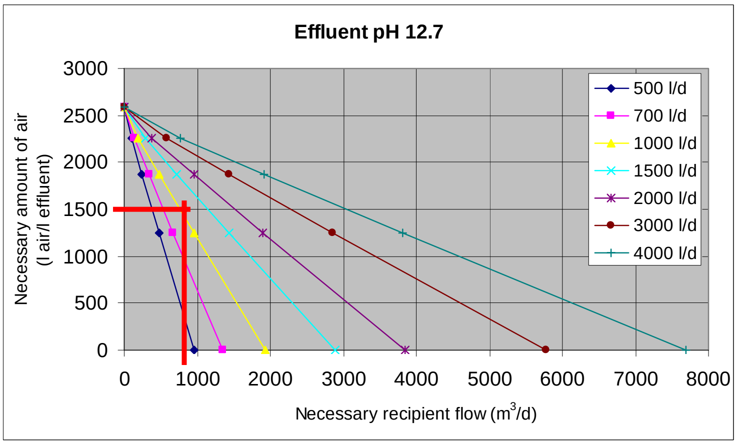
The different lines in the figures describe different flows of effluent in l/d (litres/day) for an effluent pH of 12.7 and pH 11, and the required amount of air and recipient flow.

The entry values that are needed will then be effluent flow (l/d) from the Filtralite P plant and flow in the recipient (m^3/d). When these values are obtained for a particular situation, the necessary amount of air to keep the pH below 8.5 in the receiving recipient can be found from the figures.

Air must be added before the effluent is directed to the recipient. To use a blower in the outlet well for aeration is a good alternative.

Example:

A one-house system produces about 1000 litres per day (5 persons of 200 litres) with a pH of 12.7. If this effluent were only to be diluted by the recipient, it can be seen from the figure below that the needed flow in the recipient would be about 1900 m^3/d to obtain a final pH below 8.5.



In this case the flow in the recipient is only 800 m^3/d (9.3 litres/second). The line representing 1000 l/d of effluent intersects with a recipient flow of 800 m^3/d at about 1500 litres of air/litre effluent (see the red line in the figure).

For the pH of the receiving water not to exceed 8.5, about 1500 litres of air/litre of effluent must be added in this case.

Equations:

The equations below can be used to calculate the amount of air when entering effluent flow and recipient flow.

pH 12.7

$$A = -\left(\frac{1350}{E}\right) \cdot R + 2590$$

pH 11

$$A = -\left(\frac{1350}{E}\right) \cdot R + 52$$

Where *A* is amount of air in litres/litre of effluent, *E* is effluent flow in litres/day (l/d) and *R* is recipient flow in cubic metres/day (m^3/d).

If negative values are obtained there is no need for aeration.

All calculations are based on the requirement of a final pH below 8.5 in the receiving recipient.

The values presented are based on calculations and a number of assumptions. Differences in water quality, plant design, plant operation and other things will influence these values. Therefore, what is presented here must be looked upon as guideline values.

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