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# Exceeding Tertiary Standards with a Pond/Reed bed System in Norway

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**Abstract**

At Vidaråsen in Norway sewage from a community consisting of 160 people, including a dairy, a food processing workshop, a bakery and a laundry is treated using a pond/reed bed system. The system consists of sludge settlement, pre-treatment surface/ vertical-flow constructed wetlands, a 5 m deep enhanced facultative pond, 3 stabilization ponds, a planted sand filter and finally two horizontal-flow constructed wetlands filled with lightweight aggregate (Filtralite-P). The enhanced facultative pond and the primary stabilization pond are equipped with Flowform-cascades, which provide year-round aeration, rhythmical treatment and mixing of wastewater in the ponds. Treatment performance during the first five years has been high and unaffected by harsh winter conditions. Average phosphorus discharge from the system is 0,25 mg/l with total nitrogen 4 mg/l, total organic carbon (TOC) 5 mg/l and thermo tolerant coliforms < 100/100 ml. The system is ecologically diverse and supports abundant populations of higher aquatic life such as ducks, amphibians and carp.

**Keywords**

Cold climate, ponds, vertical flow wetlands, horizontal flow wetlands, Flowforms, nutrient removal, aesthetics.

## INTRODUCTION

When the existing conventional sewage system at Vidaråsen (a therapeutic Camphill community with adults with mental handicaps) had to be replaced, the community was keen to build a system with aesthetic and educational value, thus encouraging a sense of involvement and a raised awareness amongst residents.

Because of sensitive recipients Norway has strict effluent limits, especially for phosphorous. Over the last ten years considerable progress has been achieved in the development of constructed wetlands which manage not only high removal of nitrogen, but also of phosphorus due to the use of filter media with high adsorption capacity (Zhu et al. 1997, Jenssen and Krogstad 2002). However, both nitrification and phosphorus removal require aerobic conditions in the wetland and performance is reduced when organic loadings are too high or oxygen levels fall too low. Aerobic treatment before constructed wetlands is therefore considered necessary for consistent performance in Norwegian conditions (Jenssen et al.1993, Jenssen et al. 2005). Research carried out at Solborg Camphill Village in Norway showed that wastewater stabilization ponds aerated by Flowforms (Gee 1980, Wilkes 2003) provided an effective means of aerobic treatment in temperatures of -10° C and with 50 cm of ice cover on the ponds (Jenssen et al. 1991). Jenssen et al. suggested that a system incorporating ponds and Flowforms, followed by constructed wetlands, could achieve high standards of treatment in addition to being aesthetically attractive as a landscape feature. The system at Vidaråsen, completed in 1998, is based on this combination and includes an innovative enhanced facultative pond (EFP). Results from the first five years of operation are given in this paper.

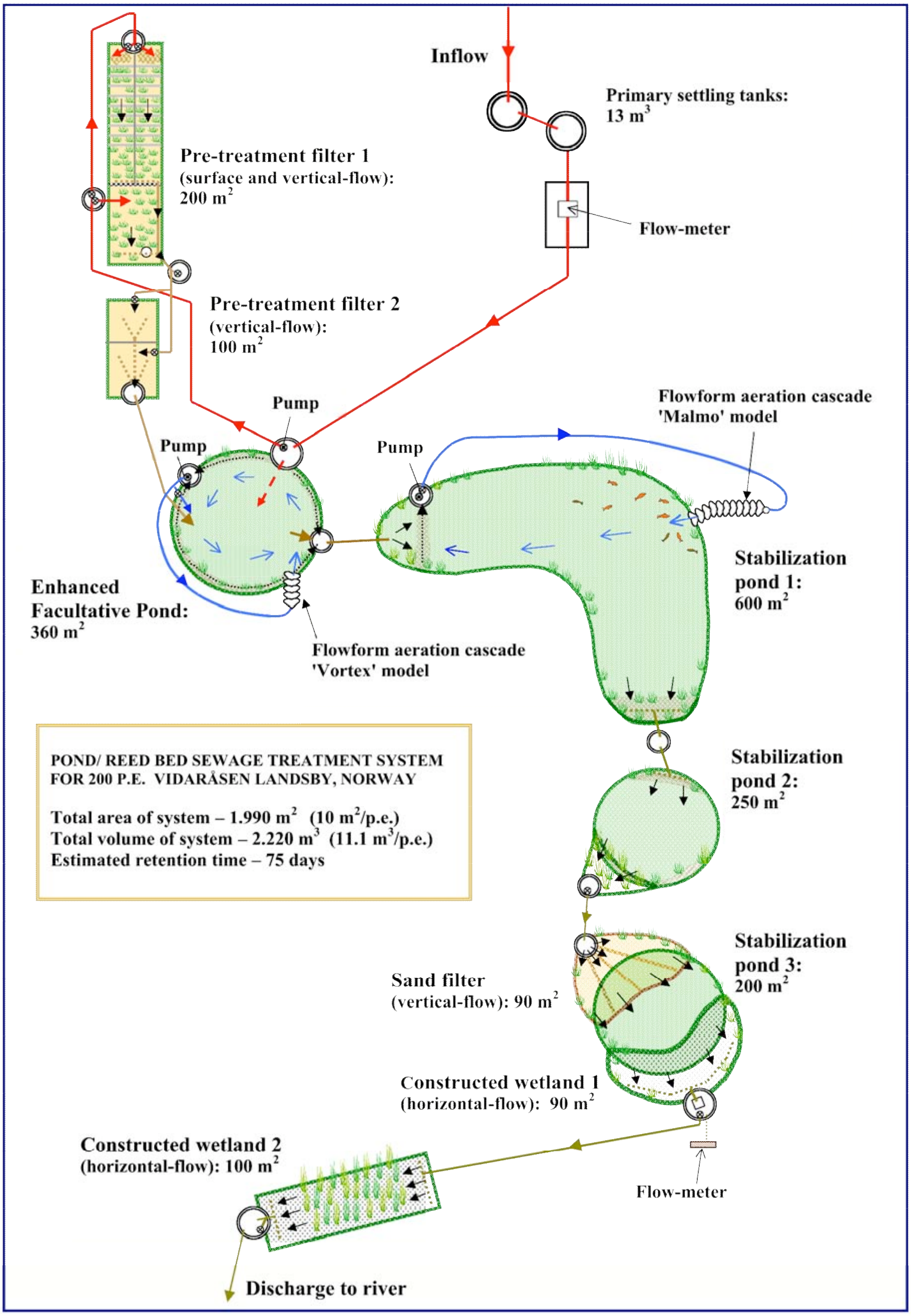

*Figure 1. Layout of the wastewater treatment system at Vidaråsen.*

## DESCRIPTION OF THE SYSTEM

Vidaråsen is situated 100 m above sea level in forested hills in the south east of Norway, approximately 100 km south of Oslo and 25 km from the coastal Oslo Fjord. The climate is typical for inland southern Norway with cold winters (-5 to -25° C) and short warm summers (15 to 25° C). Average annual precipitation is 1035 mm. The system treats wastewater from 160 residents, plus effluent from a bakery, creamery and laundry. The estimated loading of the system is 200 pe, with an average flow-rate of 30 $m^3$/d.

The system consists of six treatment stages (Fig. 1):

1. Two primary settlement tanks.
2. Two pre-treatment filters (vertical-flow wetlands).
3. An enhanced facultative pond (EFP) with Flowform aeration.
4. Stabilization ponds 1, 2 and 3, (Pond 1 with Flowform aeration).
5. A planted sand filter.
6. Two constructed wetlands with lightweight aggregate (Filtralite P).

Wastewater from the village passes first through 2 settling tanks before being pumped to the two vertical-flow wetlands. The first pre-treatment filter consists of three sloping, planted beds of 30 cm sand over 30 cm of graded gravel (Ø 5-8/ 11-16mm). Intermittent loading of the filter is achieved as the pump operates on a float valve and delivers batches of 3 $m^3$ at a time. Each bed is loaded for one week at a time and the hydraulic loading for the total area is 15 cm/d. The second pre-treatment filter is gravity fed and consists of two level beds of 50 cm of filter sand over 30 cm of graded gravel (Ø 5-8/ 11-16mm). Each bed is loaded for one week at a time and the hydraulic loading for the total area is 30 cm/d. Both filters have aeration/drainage pipes in the floor of the bed and filter 2 is covered with 30 cm of straw in the autumn to provide protection against frost.

The EFP is excavated to a circular plan and has a 1 m deep and 3 m wide gravel filter running round the edge. In the centre of the pond there is a square shaped zone of 5 m depth. The deep zone of the EFP is an unusual feature in Europe and is based on results of (Oswald 1991), who has developed facultative ponds which digest sludge much more rapidly and require less area than traditional facultative ponds. The water in the pond is continuously circulated and aerated by means of a pump that draws water through perforated pipes in the gravel filter around the pond feeding a Flowform aeration cascade that is set into the bank of the pond. The cascade is positioned in a tangential relationship to the edge of the pond so that the returning water effects a slow circular rotation in the upper levels of the pond. The pond is designed for anaerobic digestion in the deep zone, while achieving aerobic conditions in the upper levels. The Flowform cascade in the EFP consists of five identical concrete basins of the "Vortex" model which has a capacity of 300 l/min.

Pond 1 is "L" shaped and has an aeration cascade of eleven Flowform-basins of the 'Malmo' model at the outer bend of the pond. Pond 2 and 3 have gravel filters at inlets and outlets to encourage a more uniform flow through the pond and to disrupt direct channelling of water that reduces the retention time and thereby the efficiency of the pond. The gravel filters also inhibit algal migration out of the pond and provide oxygen-reduced zones. Controlled outlets have been installed to all ponds to provide buffer retention during times of high rainfall or snow melting.

From the outlet chamber of pond 2 the water is discharged across the surface of a planted sand filter consisting of four beds of 35 cm of sand over graded gravel before entering pond 3. Each bed is loaded for one week at a time and the hydraulic loading for the total area is 0.33 $m^3$/d. The final treatment stage consists of two horizontal-flow wetlands (CW). The first CW is 18 m wide, 5 m long, 1 m deep and is integrated into the edge of pond 3. The second CW is 5 m wide 20 m long and

1 m deep. Both wetlands are filled with a lightweight aggregate (LWA), known as Filtralite P. This material, which has a granular structure and graded fraction of 0,5-4,0 mm, has been shown in both laboratory tests and trial systems to provide high levels of phosphorus sorption (Jenssen and Krogstad 2002). Adsorption capacity of the media is finite and requires replacing when saturation is reached. Estimated time scales for replacement depend on levels of phosphorus entering the system but can be predicted at 7 to 10 years. LWA saturated with phosphorus is well suited for agricultural applications (Krogstad et al. 2000, Kvärnstrøm et al. 2001).

## TREATMENT PERFORMANCE - RESULTS AND DISCUSSION

During the first six months of operation (winter season) the system showed average removal results of phosphorus (P) 89 %, nitrogen (N) 68 % and total organic carbon (TOC) 76 %. Modifications were then implemented to remove surface water entering the system, increasing flow rates through the Flowform-cascades and implementing the pre-treatment filters which were originally intended for on site sludge treatment. Treatment levels improved rapidly and after five years of operation average percentage reductions are P 96 %, N 92 % and TOC 94 %. Table 1 shows that the major removal occurs in the pre-treatment filters and the EFP. The three consecutive ponds and the constructed wetlands serve to polish the effluent to an extremely high quality.

*Table 1. Average inlet and effluent concentrations from the various treatment stages (mg/l).*

| Parameter | Inlet** | Pre-filter | EFP | Pond 1 | Pond 2+3 | CW*** |
|---|---|---|---|---|---|---|
| Total - P | 6,8 | 3,6 | 2,16 | 0,88 | 0,52 | 0,25 |
| Total - N | 49,1 | 28,2 | 13,7 | 6,51 | 4,42 | 4,07 |
| NH4 | 46,1 | 10,9 | 3,2 | 0,33 | 0,24 | 0,13 |
| TOC | 84,6 | 18,8 | 7,81 | 6,38 | 5,03 | 4,86 |
| SS | 130 | 39 | - | - | 5 | <3 |
| TCB* |  | >2000 | 1200 | 100 | 50 | <10 |

* Thermo tolerant coliform bacteria /100 ml, ** after settling tank
*** Constructed wetlands.

### Phosphorus (P)

Phosphorus reduction (Fig. 2) has been the most critical test for the system at Vidaråsen because of the strict discharge consent of 0,4 mg/l and the perceived limitations of pond systems with relation to phosphorus removal, without chemical precipitation. For this reason Filtralite P was chosen as a filter media in the final wetlands. The main mass removal of P occurs however in the sand in the pre-treatment filters. These have a finite capacity and the sand was replaced after four years when P saturation appeared to have been reached. Results also show surprisingly high levels of phosphorus reduction in the ponds and especially in the EFP and pond 1. The research project mentioned earlier at Solborg (Jenssen et al. 1991) showed increased phosphorus removal during winter, a phenomenon that has been repeated at Vidaråsen. Explanations of this unexpectedly high removal at this stage are not so simple and would be worth further research. The importance of aerobic conditions in the upper levels appears to be critical however, as shown by tests from the first six months when anaerobic conditions occurred for a period under ice cover and inhibited P-reduction (Hensel 1999). In the wintertime the discharge consent for P is met at the outlet of the last pond. In the summer however the constructed wetlands with Filtralite P is needed to reduce the P-concentration to acceptable levels.

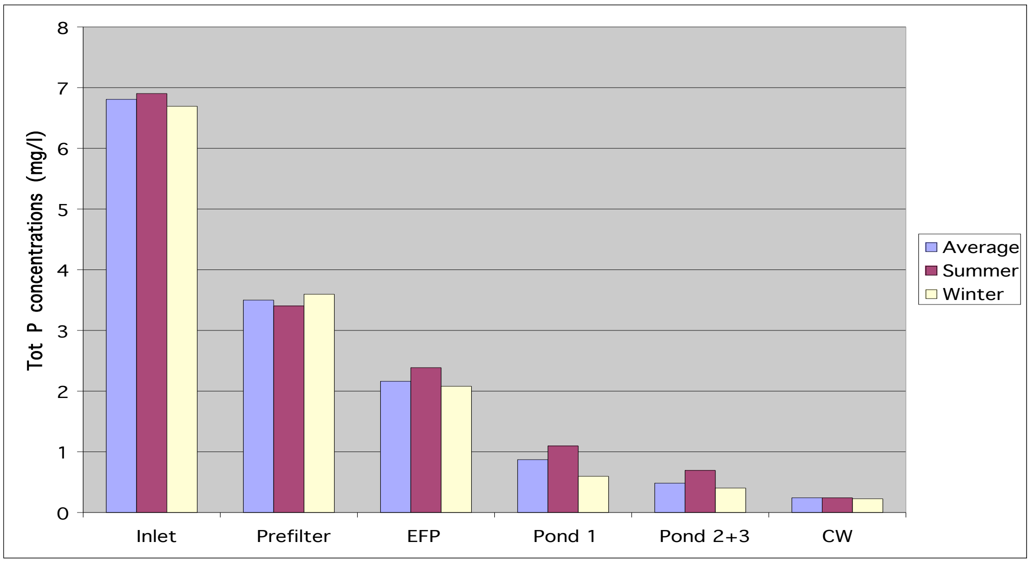

*Figure 2. Concentrations (mg/l) of total phosphorus at different stages of the treatment plant.*

## Nitrogen (N)

Nitrification takes place in both the pre-treatment filter and the EFP (Table 1). These processes are directly temperature dependent and treatment levels are higher in summer than in winter. Nitrogen removal happens mainly in the pre-treatment wetlands, EFP and stabilization pond 1 (Fig. 3). The removal in the vertical-flow wetlands can be explained by rapid nitrification and subsequent denitrification in anaerobic zones, where a carbon source is available for instance in the clogging layer of pre-treatment filter 2. Up to 45 % N-removal in sand filters has also been observed earlier (Jenssen and Siegrist 1988, and 1990). The circulation system in the EFP drawing aerated water through a submerged filter, then aerating it again, could be an effective nitrogen removal process. However the most effective N-reduction in the EFP probably occurs when nitrate from the pre-treatment filters enters the lower anoxic nutrient rich zone of the EFP. The N-removal in stabilization pond 1 may be due to reduced oxygen concentrations in the lower level of the pond and in the gravel filter at the outlet.

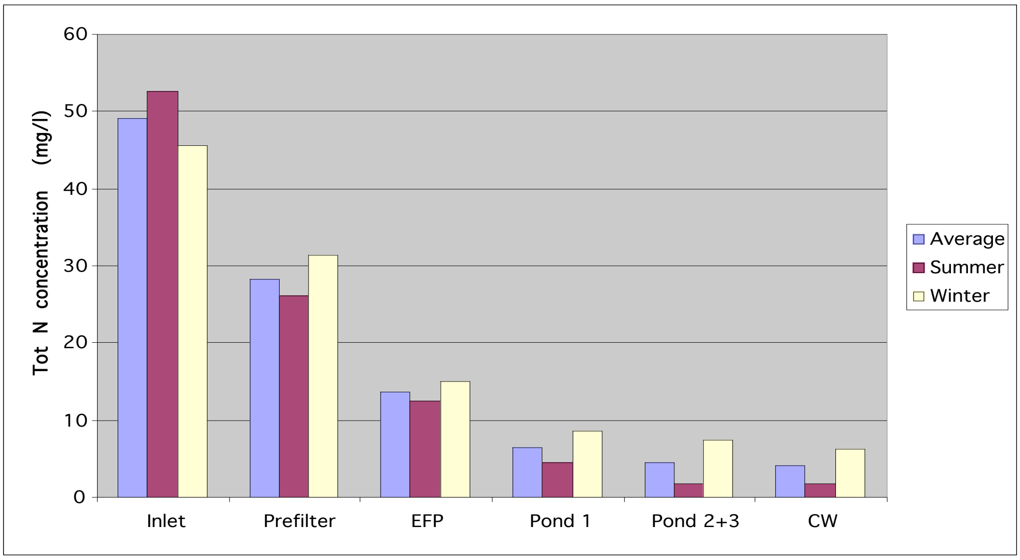

*Figure 3. Concentrations (mg/l) of total nitrogen at different stages of the treatment plant.*

Some nitrogen may be removed from the system through harvesting of duckweed in the ponds, which is repeatedly carried out from June until October. Tests made on duckweed taken from the system showed high levels of nitrogen (3592 mmol/kg of Kjeldahl-N) in the dry bio-mass (Hensel 1999). Ammonia levels are very effectively reduced in the early stages of the system as a result of nitrification (Table 1). By the outlet of the constructed wetland ammonia has been almost eliminated. The concentration of nitrogen in the final effluent meets the World Health Organisation (WHO) drinking water standards.

### Organic matter (TOC)

Treatment performance in relation to organic material has been measured in accordance with the discharge consent as total organic carbon TOC rather than BOD. The consent level of 10 mg/l is already attained at the outlet of the EFP with less than half this level in the final effluent. Reduction of TOC in the pre-treatment system is 78 %. This is no surprise, as intermittent vertical-flow sand filters are known to efficiently reduce organic matter (Jenssen and Siegrist 1990). The ponds show better results during winter than summer, which can be explained by carbon in the form of algae in suspension during the growth season.

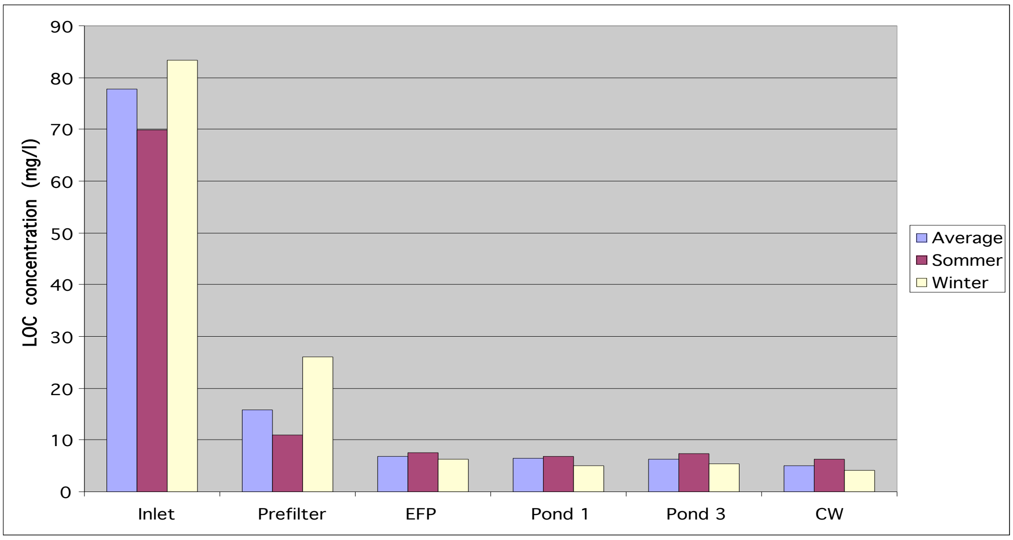

*Figure 4. Concentrations (mg/l) of total organic carbon at different stages at the treatment plant.*

### Pathogen Removal

Pathogen removal in the system at Vidaråsen has been assessed by testing for thermo tolerant coliform bacteria (TCB). As could be predicted for a system with a long retention time, removal rates are very high with levels in the final outlet chamber consistently under 10 TCB per 100 ml throughout the year. This concentration meets the Norwegian standard for excellent swimming water of < 100 TCB/100 ml. Parasites and their eggs, which have been shown to survive for longer periods in treatment systems (up to seven years), will have been filtered out in the pre-treatment filter owing to the relatively large size these micro organisms (Jenssen 1988).

### Suspended Solids

Long retention time and repeated filtration provide high reduction of suspended solids in the system at Vidaråsen (Table 1). Problems associated with algal suspension in the final effluent have been reduced by the presence of a gravel filters at the outlets to the stabilization ponds. Shading of the surface of pond 3 in order to reduce algae has been achieved by the growth of floating leaved plants such as *Potamogeton natans.*

### Maintenance and Operation of the system

While the system at Vidaråsen does not require high levels of technical maintenance, it does require regular attention to ensure effective performance. The most maintenance demanding parts of the system are the pre-treatment filters, which need weekly visits to regulate loading of the different sections. The application and removal of straw, together with digging/raking of the surface of the filter are relatively labour intensive. Other regular maintenance tasks include monthly scrubbing of the Flowforms to remove bacteria and algal growth, checking operation of pumps and flow meters, and the removal of duckweed. Harvesting of duckweed from the ponds is necessary for ensuring aerobic conditions and algal activity, while also achieving some level of nutrient removal. The task is effectively carried out using floating ropes and specially made rakes. Attention to plant growth both in and around the system is needed to create a balance between functional, ecological and aesthetic requirements.

### Aesthetic and Ecological Considerations

A public footpath runs next to the treatment system, which provides a much-used vantage point for visual appreciation of the system. The open stretches of water bordered by flowering banks of irises and rushes, together with the sound of the water circulating in the Flowforms creates a popular attraction. Smell is hardly noticeable under normal conditions and visitors are often surprised that they are at a sewage treatment system. Health and safety considerations require of course that the system is securely fenced. Pond systems have other impacts on a locality and can increase considerably the ecological diversity. The system at Vidaråsen provides a habitat for a huge range of insects, amphibians and higher animals.

### The Role of Plants in the System

At Vidaråsen various plants have been used at each stage of the system for specific tasks. In the pre-treatment filters, *Phragmites australis, Scirpus sylvaticus and Urtica dioica* have been used to re-condition the sand media between loadings. *Scirpus sylvaticus* has an unusually long growing season even in cold climates and *Urtica dioica* appeared by itself and has colonized densely. It appears to assist a rapid opening up of compact saturated media and promotes earthworm activity in the filters. The ability of *Phragmites* to support aerobic conditions in heavily loaded subsurface wetlands has been widely documented (Schierup and Brix 1990) and is for this reason used in both the pre-treatment filters and the filter around the edge of the EFP.The edges of the ponds are densely planted with a wide range of marginal aquatics including *Typha latifolia, Carex, Sparganium erectum, Butomus umbellatus* and *Glyceria maxima*. These plants provide habitats for insect species such as dragon flies, but also refuge for microorganisms during unfavourable conditions, allowing rapid re-colonization when factors are in balance again. Floating leaf plants such as *Potamogeton natans* can be useful for shading sunlight from the final pond, thus reducing algal activity and the risk of migration in the final effluent. Common duckweed (*Lemna minor*) is an extremely prolific species once water temperature reaches 7° C. If the growth of duckweed is allowed to proceed unchecked, oxygen levels in the ponds and algal growth will be seriously depleted. Regular harvesting meanwhile may achieve some removal of nutrients.

## CONCLUSIONS

Results from the first five years of operation of the pond/reed-bed system confirm the indications of excellent removal capacity from earlier studies. Other advantages such as low-skilled maintenance, high buffering capacity of seasonal or shock loadings and long retention times enhancing pathogen removal, provide the basis for renewed interest in the potential of pond systems in wastewater treatment in cold climates. Effluent quality meets the European requirements for swimming water, regarding indicator bacteria, and the WHO drinking water requirements regarding nitrogen are achieved.

The system is relatively area extensive (10 $m^2$/pe), but the results show that by combining ponds, Flowforms and constructed wetlands, year-round treatment is achieved to an extremely high standard even for phosphorus. This indicates that new systems using the same concept could be built considerably smaller and still meet standard treatment requirements. Other important advantages with this system are potential reuse of nutrients through recycling of P-saturated sand and light weight aggregates, irrigation and plant biomass composting, as well as educational and ecological benefits. This should make such treatment options more attractive, especially in remote or out-lying villages and tourist developments.

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