

Short communication

Wastewater treatment by greywater separation: Outline for a biologically based greywater purification plant in Sweden

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Abstract

The current system of wastewater treatment in industrial societies severely restricts the possibility of nutrient recycling. One of the biggest constraints is the mixing of the part of the sewage water containing a high concentration of nutrients with greywater, which contains fairly low amounts. The MIx-First-and-Separate-LATER (MIFSLA) approach to waste water management has led to a wastewater system the function of which is to first mix and then to remove urine and faeces from the greywater. The aim of this article was to analyse this problem and to propose a method for wastewater treatment where the different components of the wastewater are treated according to their individual qualities. The focus is placed on the treatment of greywater with ecotechnological methods. The greywater purification plant is designed to enhance the subsurface flow of water and biological interactions of plants and microorganisms in a triplicate riparian ecotone. Preliminary calculations of the efficiency of such a system indicate that the residual nutrient content of the water would be about 0.06 mg N l^{-1} and 0.02 mg P l^{-1} , which is less than 1/10 of drinking water standards. After one year of use, tests have given the results of $0.007 \text{ mg N l}^{-1}$ and 0.02 mg P l^{-1} . Bacteria was reduced with 3–4 powers of ten (to detection level) in the pond system, and not detected after final treatment. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

As a consequence of urbanization, food production and settlement areas have become sepa-

rated. This implies that nutrient flows have changed from being fairly circular and local to linear and global. Instead of being recycled, plant nutrients are exported with food from agricultural areas to urban areas, and end up in waste dumps or agriculture near the urban areas. The large disproportion between the amount of inhabitants and the available of farmland in urbanised areas

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makes recycling physically impossible. Thus, the human waste, i.e. urine and faeces, is considered a nuisance to be disposed of.

To counteract point source pollution, advanced wastewater treatment plants with phosphorus reduction have been introduced. Water is used as a transportation media in an extensive piping system. In the majority of the plants in Sweden, the phosphorus is reduced by about 92% (Sundberg, 1994). This does not mean that the phosphorus is eliminated. Instead, it accumulates in the urban area to cause a future non-point pollution (Günther, 1997). The high N/P ratio in the purified sewage water is a major problem to coastal recipients.

Thus, the current system of wastewater treatment severely restricts the possibility of nutrient recycling. The bigger constraint evolves when the wastewater from toilets that contains a high quantity of BOD and nutrients (urine and faeces) is mixed with greywater (from washing, dish, bath water and the like), which contains fairly low amounts. The MIX-Firststand-Separate-LATER (MIFSLA) approach to waste water management has led to a system (Table 1) that may be described in the following way:

- Clean water is mixed with urine and faeces to a polluting mixture of plant nutrients and pathogens.
- This mixture is in turn mixed with fairly clean greywater.
- The resulting mixture is diluted with drainage water in an extensive web of sewage pipelines.
- Finally, the mixture is purified to a quality comparable with that of the original greywater, but with a doubled volume.

Hence, the actual function of the wastewater system is to remove urine and faeces from the greywater, a function that can be attained easier by the use of source separating toilets.

By the use of ecological engineering methods, i.e. recognising the self-designing properties of natural ecosystems and recognizing the multiple values of these systems combined with the design of human societies with its natural environment for the benefit of both (Mitsch and Jörgensen, 1989), these problems can be solved. The aim of this article is to analyse this and to propose a

method for wastewater treatment that does not include mixing of excrements and greywater, combined with the use of an instituted self-organising ecosystem to purify the resulting greywater.

1.1. Current waste water treatment system

There have been surprisingly few figures in the literature regarding the amount of nutrients in urine and faeces. A list compiled by the Swedish EPA (SNV, 1995) has been used to calculate average amounts of nutrients in the different fractions of wastewater in Sweden (Table 1).

2. Source separation of greywater

Urine is a valuable nutrient resource with about 90% of the nitrogen and 67% of the phosphorus in the human excrements (as can be calculated from Table 1). Source separating toilets are available under different trademarks in Sweden. They transfer urine to a tank for a subsequent recycling on agricultural land.

Regarding the treatment of faeces, the source separating toilets can be classified into two different types. One type (the 'dry' type) collects the faeces in a composting chamber for the elimination of pathogens during a 6-month composting process. The other type (the 'wet' type) uses water for the transport of faeces to a tank or uses a device for subsequent separation of flush water and faecal matter. In some cases, this fraction is let out to the conventional system. Urine separating toilets have recently been discussed in the literature as a solution to the wastewater problem (e.g. Hanaeus et al., 1997; Hellstrom and Karman, 1997; Jonsson et al., 1997; Drangert, 1998).

Regardless of type, a main advantage of the source separating toilets is that the *greywater* remains uncontaminated by faecal matter and urine. Until recently (Bingley, 1996; Jeppsen, 1996; Nolde, 1996), this quality of the source-separating toilet has remained unnoticed.

As can be seen in Table 1, the greywater has about the same quality as the water released from the wastewater plant *after* purification, i.e. regarded as clean by normal standards. However,

Table 1

Average per capita amounts of P and N in the wastewater from a person living in Sweden compared with water after purification in a standard sewage plant^a

	Urine	Faeces	Grey water	Waste water plant	
				Before purification	After purification
Volume (l pers ⁻¹ day ⁻¹)	1.12	0.15	199 ^b	397 ^c	396
N (g pers ⁻¹ day ⁻¹)	11.0	1.5	1.0	13.5	10.2
P (g pers ⁻¹ day ⁻¹)	1.0	0.5	0.6	2.1	0.1
Volume (l pers ⁻¹ year ⁻¹)	409	56	65 386	145 023	144 658
N (kg pers ⁻¹ year ⁻¹)	4.0	0.6	0.4	4.9	3.7 ^d
P (kg pers ⁻¹ year ⁻¹)	0.4	0.2	0.2	0.8	0.1
N-conc. (mg/l)	9810	9811	5.0	34.0	25.6 ^d
P-conc. (mg/l)	892	3270	3.0	5.3	0.4
N/P-ratio ^e	11	3	2	6	72
Notes	Primary sterile	Possible pathogen content. High dry mass.	Low concentration of pollutants	Input of water from other sources	Risk for viral pathogens and nitrogen pollution

^a Note that the volume of water is greatly increased during the transport from the house to the sewage plant due to leakage of drainage water into the pipes and from other sources).

^b A figure of 199 l (150 l grey water plus 49 l toilet flush) has been used. (SNV report 4425).

^c In a report regarding 23 of the largest sewage plants (A-plants) in Sweden, serving 40% of the population (Sundberg, 1994), the total amount of water actually purified is about 400 l pers⁻¹ day⁻¹. In order to attain consistency with these figures, one has to assume an average extra flux of water of about 217 l per person per day into the sewage pipes from drainage water or leakage.

^d This figure is calculated for a wastewater plant without extra nitrogen reduction. With extra reduction, it could be 2.5 or 1.2 kg pers⁻¹ year⁻¹, depending on the extent of purification.

^e An N/P of around 10 is optimal for nutrient uptake by plants. If this figure is below 10, nitrogen is the limiting substance, leading to a sub-optimal phosphorus uptake unless the plants can get nitrogen from other sources. If the ratio is far above 10, the reverse is true.

the content of nitrogen compounds in the purified wastewater is considerably higher, even after extended nitrogen purification. Because of its low grade of pollution, greywater can be handled in a much easier way than the MIFSLA wastewater.

3. Biological treatment of greywater

The main problem with the greywater may be its large volume, which in Sweden is about 65 000 l pers⁻¹ year⁻¹. A treatment plant therefore needs ponds of a large size for the accommodation of the water.

Another problem might be the low temperature that might occur during wintertime, with low biological activity and potentially decreased water conductivity related to frost. To counteract these

two problems, there are two main routes to be chosen. One is to place the entire system beneath a glass roof and heat it during the winter, which implies very high construction and maintenance costs. Another approach is to accept the occurrence of low winter temperatures and prolong the turnover time of water in the system to 1 year. By doing so, even water entering the system in mid-autumn will remain during a summer period in the system.

However, the problem of an interrupted biological activity due to winter frosts seems to be rather small. Mander et al. (1991) compared the nutrient reduction capacity of vegetated bioponds during the vegetation period and in winter. They found that the reduction capacity for P, N and BODs was only reduced with 88–65% during the winter period. The depth of the beds is chosen to avoid

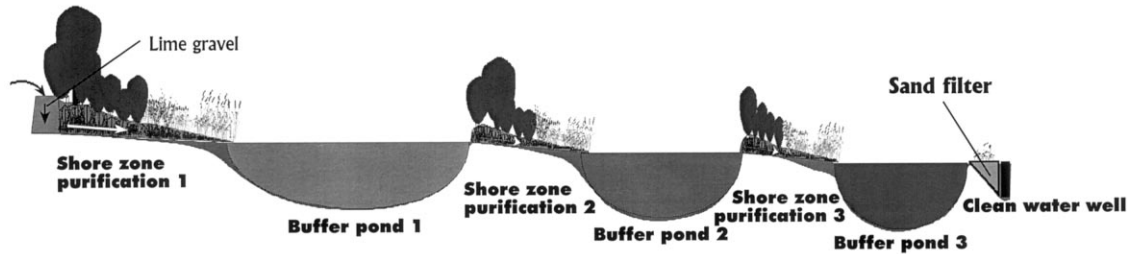


Fig. 1. An outline of the triplicate shore-pond system for greywater purification.

the problem of freezing, which would clog the system.

4. A triplicate soil layer infiltration-wetland-pond system for greywater purification

4.1. General principles

A greywater purification plant was designed to encourage the subsurface flow of water and to enhance interactions of the plant and microorganisms occurring in a normal riparian ecotone as studied by Mander and Mairing (1995). Because of its managed, park-like composition and its wetland type structure, the name of the purification system is proposed to be a *wetpark*. Water is let in under the roots of the planted vegetation and stored in a pond to be fed into consecutive shore. This is repeated three times to increase turnover rate and, by that, attain a large reduction of incoming pathogenic bacteria, BODs and nutrients (Fig. 1). After the last pond, the water is let into a sand filter system and is collected in a well.

Before entering the pond system, the water passes through a section filled with lime-gravel to increase the surface for organic material reduction by aerobic bacteria and to buffer pH. The water is distributed over this bed by means of the spread of inlet pipes over the upper surface of the gravel bed.

In order to be able to establish the system on soil with large infiltration capacity, a waterproof

layer is placed under the purification plant. For longevity, bentonite¹ mats were chosen.

The plant species that are chosen to be introduced into the wetpark system are those prevailing in the normal wetlands in the region. Plants with nitrogen fixing root nodules, as *Alnus*, are suitable because of their capacity to extract phosphorus from waters with a low N/P ratio. *Salix spp.* species and the species of the *Aegopodium podagraria*-*Filipendula ulmaria*-*Cirsium oleraceum* plant community are chosen because of their capacity to extract nutrients and thrive in wetland conditions. On the shores of the ponds, plants like reed *Phragmites communis* and cattail, *Typha latifolia* are chosen because of their capacity to transport air in their aerenchyma down to the roots, and by that create conditions favourable for denitrification, should it be needed. The plants will be continuously harvested and composted, in order to remove nutrients from the system. Also, some fishes and crayfishes are introduced into the ponds, in order to control insect larvae and digest leaf litter and other organic matter.

Due to the long turnover time, the slow flow, and the long underground passage, the reduction of bacteria and viruses emitted with the greywater would be almost complete. Green et al. (1997) reported a 3-log reduction of *E. coli* at a retention time of 5 days, Williams et al. (1995) a 2-log

¹ A clay, largely consisting of montmorillonite, formed by the decomposition of volcanic glass. It is very impermeable to water. It is commercially available enclosed in mats for water sealing.² This hypothesis is encouraged by the observation of *Cladophora* growth in Pond 3, but not in the preceding Pond 2.

reduction in tertiary treatment with the retention time of 1 day. In the plant discussed in this paper, the retention time in the first sand bed is about 30 days, and the total retention time about 1 year.

4.2. Practical application

A new building at the technical university college of Kalmar, South Sweden, has been equipped with a greywater separating system, and connected to a wetpark system. The intention is to purify the water to a quality that would allow re-use in the building. The house is designed for 500 students, with a total water use of about 400 m³ per year. The water is very lightly polluted, it is only used for hand- and dishwashing. The area requirement for the plant is about 1200 m², which is almost the same as the roof area of the building.

Also rainwater from the roof of the building is let into the wetpark. The amount of purified water will therefore be larger than what is needed in the building, why the building–wetpark system therefore can function as a *net exporter* of clean water. The export capacity is about 700 m³ purified water per year.

In the Kalmar plant, there was concern regarding hazards for children created by the pond-based plant. The possible danger of deep ponds was eliminated by the introduction of a ‘pseudo-bottom’, an extra bottom of porous material (in this case macadam, but damaged concrete pipes would do the job better), within which the water could circulate. This could combine the seemingly contradictory goals of a low water level and high water content within a small area. An effect of this was the necessity to have the water continuously pumped through the pseudo-bottom. This provides an extra purification capacity due to the microorganisms settled on the stones. However, the amount of electricity used for pumping of water through the stone layer is considerable.

The system was completed in August 1997, and an research programme for assessing its performance is under development. Practical results

for system efficiency are yet to be measured. However, preliminary calculations (assuming a 75% reduction of nutrients for each passage of a shore-zone) indicate that the residual nutrient content of the water would be about 0.06 mg N l⁻¹ and 0.02 mg P l⁻¹. This is about 1/10 of the drinking water standards (SLV FS, 1993).

The construction cost of the wetpark system is about 3000 SEK (\$ 375) per connected person. This figure include the cost of paths, seats and walls and other equipment to increase the aesthetic value of the purification plant, an aspect that should not be underestimated. For normal use in connection to an ordinary group of houses, it should be possible to diminish the cost considerably.

5. Results

During the first year of use, preliminary measurements were made. The tests were made for faecal streptococci, thermostable coliform bacteria, BOD₇, P and N. These samples were not made as part of a research programme, but to comply with the requirements of the local environmental health office. Since the turnover time of the water is about 1 year, samples that more decisively show the result of the purification method will not be available until the end of 1999.

5.1. Bacteria

Only fecal streptococci and thermostable coliform bacteria were analysed. The results show a 2–3-log reduction of bacteria from the passage of the first shorezone. In the following ponds, there seems to be a further reduction in the size of another power of ten, but since a large part of the samples were assigned the value ‘below detection level’, these figures are not decisive. Only one sample was taken indoors, in the returned water due to a delayed start of use of the water. In this sample, bacteria were not detected (Tables 2 and 3).

Table 2
Fecal streptococci, count/100 ml

	Greywater	Pond 1	Pond 2	Pond 3	Reception well	Inside
<i>n</i> =	13	17	3	6	9	1
Average	35 848	361	432	15	43	0
Sdev	34 732	553	478	12	53	–
50% Conf	6497	90	186	3	12	–

Table 3
Thermostable coliforms, count/100 ml

	Greywater	Pond 1	Pond 2	Pond 3	Reception well	Inside
<i>n</i> =	14	17	3	6	9	1
Average	94427	25	96	11	172	0
Sdev	130 164	37	52	12	295	–
50% Conf	23 464	6	20	3	66	–

Table 4
BOD₇, (mg/l)

	Greywater	Pond 1	Pond 2	Pond 3	Reception well	Inside
<i>n</i> =	14	17	3	6	9	1
Average	47	0.5	0	0.8	0	0
Sdev	25	0.9	0	1.3	0	–
50% Conf	4.5	–	0.1	n/a	0.3	n/a

Table 5
Nitrogen (mg/ml)

	Greywater	Pond 1	Pond 2	Pond 3	Reception well	Inside
<i>n</i> =	6	6	0	1	5	1
Average	3.72	0.975	–	1.900	1.618	0.007
Sdev	2.21	0.917	–	0.000	1.546	–
50% Conf	0.61	0.252	–	–	0.466	–

Table 6
Phosphorus (mg/ml)

	Greywater	Pond 1	Pond 2	Pond 3	Reception well	Inside
<i>n</i> =	6	6	0	1	5	0
Average	3.73	0.372	–	0.020	0.022	–
Sdev	2.65	0.576	–	0.000	0.005	–
50% Conf	0.73	0.159	–	–	0.002	–

5.2. BOD₇

In the BOD₇ testing, only a few samples in the ponds (three of 36) gave detectable results. In the rest of the samples, an oxygen reduction due to metabolism was not detected. In the greywater, however, the BOD₇ level was low, but detectable (Table 4).

5.3. Nutrients

The P content of the incoming greywater was equal to the level predicted in Table 1, but the N level was lower. The nutrient level in the output water in the building was about 10% of what was predicted during the construction phase. However, the nitrogen reduction in the pond system was only around 50%, probably due to leakage from the plant soil on the shorezones and that the denitrifying vegetation is not yet established. The P reduction was about 99.5% (Tables 5 and 6).

In the sample that was taken inside the building, the nitrogen content was calculated from the NH₃-N and NO₂-N. NO₃-N was not tested here (Table 5).

6. Discussion

Future threats to environmental security and human health includes increased cost of fossil fuels (Campbell and Laherrere, 1998), with the resulting shortage of fertilizers and clean water. Thus, particular attention needs to be given to the management of water and recycling of nutrients. The development of systems for water treatment that mimic the structure and function of natural wetlands are therefore important, since they are essentially sun-driven. In this article, I have demonstrated that the introduction of wastewater systems that not mix human excrements with greywater allow simplified methods that could help solving many of the problems of modern sewage treatment.

The abandoning of the MIFSLA approach to water management leads to simpler methods of waste management, where the different components of the wastewater can be managed according to their individual qualities.

This method is not only cheaper than the conventional one, the construction of wetparks has also recreational and psychological values. The wetpark system will also provide habitats for birds and increases the biological diversity in the area.

It can be said that this is not a method for dense urban settlements, because of its area requirements (about 40 m² per person if the plant is designed to purify all grey water from a household). However, land use is often a matter of preferences. Forty square meters is about the same area as three parking lots. In the case of the Teknikhuset, the nearby park was much improved by the introduction of the pond system, both regarding esthetical values and in biodiversity.

The samples that were taken during the first year of use indicate that the water emerging from the wetpark system is fully appropriate for re-use in the building, even as drinking water. However, in this case it is only used for hand washing and toilet flushing.

The widespread notion that the nutrients in urine and faeces must be returned to agriculture in order to maintain sustainability opens to a new mode of wastewater treatment. The focus of this paper is the *greywater*, which is an effect of the introduction of source separating (non-MIFSLA) toilet systems. The use of constructed wetlands for greywater purification will be cheaper and simpler than the ordinary wastewater system using the MIFSLA method. It will also be possible to place within the vicinity of the settlement that produces the greywater — therefore the name *wetpark* of a system that is at the same time a useful constructed wetland for water purification and a park for recreational purposes. This will increase the local biological diversity and enhance the attractiveness of the area and, with proper education, increase the public awareness of ecological services.

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