# Wastewater purification in a willow plantation The case study at Aarike

V. Kuusemets and T. Mauring

Centre for Ecological Engineering, Jannseni 4, EE2400 Tartu, Estonia

## Abstract

In order to combine wastewater purification and biomass production for energy purposes, a willow plantation for wastewater treatment was established in 1995 in Aarike, Southern Estonia. Wastewater from a dwelling house (25 person equivalents, pe) is treated in a combined free-water filter system consisting of three separate basins, isolated with clay and having filter beds of gravel and sand mixture. The beds were planted with *Salix viminalis* (planting density 1 plant $m^{-2}$). At the end of the first growing season, the purification efficiency of the newly established treatment system was 65 % for $BOD_7$, 43 % for nitrogen and 11 % for phosphorus removal. At the end of the establishment year, the above-ground production of willow stems (bark and wood) and leaves was 1.3 and 0.3 t $ha^{-1}$, respectively. The figures are about three to five times higher than those recorded in previously established energy forest plantations of comparable ages in Estonia.

**Key words**: *Ecological engineering, Energy forestry, Productivity, Salix viminalis, Wastewater treatment*

## Introduction

The use of energy forests for municipal wastewater treatment has been studied in numerous papers (e.g. Obarska-Pemkowiak 1994, Perttu and Kowalik 1996). Using wastewater for energy production gives a good opportunity to recycle resources and to solve complex environmental problems. This approach is the main task of ecological engineering which deals with sustainable technologies (Mitsch and Jørgensen 1989). Energy forests have been pointed out as one of the most suitable ecological solutions for wastewater treatment (Guterstam 1991), having a low degree of treatment intensity and a high degree of recycling. Combining these two targets in practice is technically complicated. Wastewater flow is continuous and a purification system must be efficient throughout the whole year. The growing season in Estonian climate conditions lasts about six months. Natural wastewater purification systems should be designed to be efficient during the whole year. At the same time, growth requirements of willows have to be taken into consideration when using them for wastewater treatment. Considering these circumstances, willow plantations have so far been used mostly for irrigation with wastewater (Aronsson and Perttu 1994, Hasselgren 1994, Kutera and Soroko 1994, Perttu 1994).

The application of natural methods for wastewater treatment has been the main topic of ecological engineering, which has attained an acceptable level during the recent years. The use of ecosystems for wastewater treatment has shown good purifying effect in what concerns both organic matter and nitrogen and phosphorus removal (Jenssen *et.al.* 1991, Geller 1992, Brix 1994). The systems are designed in order to create a favourable environment for microorganisms which decompose organic matter and remove nitrogen. The main nitrogen removal process is denitrification. Direct nutrient uptake and accumulation in plants is relatively small (less than 10 % of the total nitrogen in wastewater, Jenssen *et. al.* 1991). Phosphorus is removed mostly by adsorption/precipitation processes, which need a large contact area of wastewater with surface particles.

Natural wastewater treatment systems can be grouped into three major types (Tchobanoglous 1991): i) land-based systems, ii) constructed wetlands, and iii) aquatic plant systems. Land-based systems may be of slow-rate irrigation type, rapid infiltration type or overland type, all of which being used as irrigation systems. Aquatic plant systems are shallow ponds with floating or submerged aquatic plants.

The most efficient systems in the long run are constructed wetlands. They have been divided into free-water surface wetland and subsurface flow wetland types. Free-water surface wetlands consist of basins or channels with emergent vegetation (mostly *Phragmites australis* and *Typha latifolia*). The main purifiers in these systems are algae and floating aquatic plants and microorganisms associated with macrophytes. Such systems have a high organic matter purification efficiency and, due to the high denitrification rate, good nitrogen removal efficiency. However, in these systems wastewater has less contact with surface, which results in a lower phosphorus removal efficiency. Purification efficiency in winter in anaerobic conditions is more problematic. This leads to the larger area requirement: more than 20 $m^2$ $pe^{-1}$ (Brix 1994). At the same time, such systems are easier to maintain.

In subsurface flow wetlands, wastewater flows through basins or channels usually filled with coarse filter material. These systems are also known as root-zone systems, plant-filters, etc. The most common plant used in subsurface flow wetlands is reed (*Phragmites australis*). Reed has a well-developed root system which is an important environment for microorganisms. Roots and rootstocks aerate subsurface and create a "drainage structure" in the soil. Subsurface flow wetlands are characterized by having a good phosphorus removal by adsorption in the soil and a smaller area requirement, about 5-10 $m^2$ $pe^{-1}$ (Geller 1992, Brix 1994). Such systems may involve problems related to hydraulic conductivity, and they are more complicated and expensive to build.

In order to use willow in wastewater treatment, several factors are to be considered: Good growth conditions for soil microorganisms should be created during the winter. At the same time, willow growth requirements must be taken into account. Because willow roots do not tolerate long-term anaerobic conditions, free-water surface wetlands cannot be used. Soil hydraulic conductivity problems do not allow use of subsurface flow wetlands.

To take advantage of different wastewater purification systems and when considering willow growth requirements, a small pilot experimental wastewater purification plantation was established in Aarike, Southern Estonia. The aim of the present paper is to describe the principles and the layout of the treatment system and to present the first-year results of the experiment, established in May 1995.

**Aarike wastewater treatment system**

The pilot wastewater treatment system at Aarike was set up in May 1995. The willow plantation was designed to purify domestic wastewater originating from a home for aged people. The amount of wastewater is equal to 25 pe, i.e. about 5 $m^3$ $day^{-1}$. Wastewater from the different buildings flow into three septic tanks with a total volume of 20 $m^3$. From the tanks, the wastewater is directed by gravitational flow onto the purification field experiment (Fig. 1).

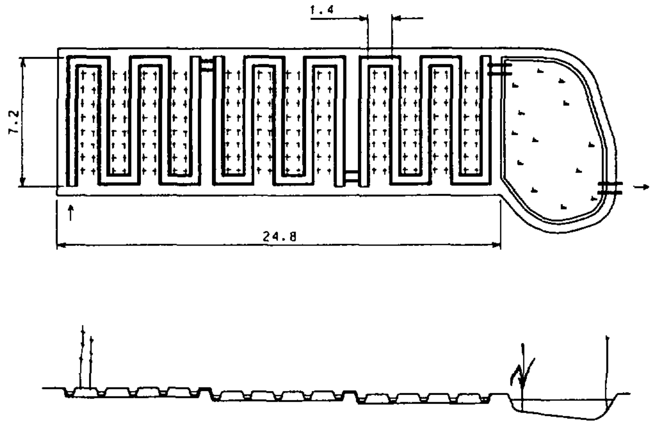


Fig.1. Aarike wastewater purification willow plantation. The distances in the figure are given in metres ┼ denotes *Salix viminalis* and ⊔ *Phragmites australis.*

The system consists of three separate basins 7.2 x 8.3 $m^2$ each. The total area of the system is 180 $m^2$ (Fig. 1). The bottom of the basins is made of several layers, the lowest of which consists 5-10 cm of gravel and 10 cm of loamy red moraine covering it. To avoid wastewater leakage into groundwater, the moraine is covered with a layer of compressed heavy clay (5 cm). The waterproof basin bottom is covered with filter material (5 cm of course sand and fine gravel). Every basin has four beds, each 30 cm high and 1.2 m wide. The beds consist of 20 cm of filter material and a 10-cm humus layer on top of it. They form a miniature serpentine channel in each basin for maximizing water contact with surface as well as for forcing wastewater flow through the beds. The beds are planted with willow, *Salix viminalis* clone 78183 (2 cuttings per $m^2$ if the calculations are based on the bed surface area alone, and 1.1 cuttings per $m^2$ if the calculations are based on the area of the whole system). The willow clone was selected within the Swedish Energy Forest Program and has been used in two previous Estonian energy forest plantations (Koppel 1994).

The described system is a combination of typical free-water and filter systems for wastewater treatment. Wastewater is filtrated through the beds via their gravel bottom and supplies the willow roots with water and nutrients. The channel serves as a free-water purification system, operating presumably also in winter. At the outflow of each basin a weir was installed for regulation of the water level. The normal water level is 15-20 cm above the bottom of the system. Prior to the cold period, the water level is raised in order to form an ice cover, and lowered again to keep up wastewater purification process under the ice cover. To achieve a final treatment step, a pond with macrophytes was built at the end of the system.

## Methods of analyses

Wastewater have been sampled once a month from the inflows and outflows of each basin and analysed in the South Estonian Laboratory of Environment Protection using standard methods for water and wastewater quality analyses (APHA 1981). The following parameters were analysed: pH, $BOD_7$, $NH_4$-N, $NO_2$-N, $NO_3$-N, total (Kjeldahl)-N, $PO_4$-P, total-P, $SO_4$, and Fe.

In the beginning of November 1995, the stem diameter of each shoot was measured at the height of 55 cm above ground and the above-ground productivity was estimated by applying stem diameter/shoot weight and shoot diameter/leaf weight correlations. This estimation was performed by the Institute of Zoology and Botany in Tartu.

## Results and discussion

### *Wastewater treatment efficiency*

The inflow concentrations of $BOD_7$ were mainly between 80 and 110 mgO $l^{-1}$, the average during the study period (May-October) being 83 mgO $l^{-1}$ (Fig. 2). The average outflow concentration was 29.5 mgO $l^{-1}$ (varying from 11 to 57). The highest (over 50 mgO $l^{-1}$) outflow concentrations were measured twice: i) in the beginning of June when the system was started and ii) in October after maintenance works when the system was temporarily emptied. In all other cases the $BOD_7$ of the outflow water was less than 21 mgO $l^{-1}$, which is below the Estonian wastewater effluent requirement level of 25 mgO $l^{-1}$ for small settlements. The efficiency was highest in the first basin where the $BOD_7$ content decreased from 83 to 47 mgO $l^{-1}$. In the outflow of the second basin the average $BOD_7$ value was 38 mgO $l^{-1}$ and, in the outflow of the third basin, 29.5 mgO $l^{-1}$. Thus the average $BOD_7$ purification efficiency for the whole system and the whole growing season was 65 %.

The main nitrogen component in the wastewater was ammonium nitrogen (80-90 % of total nitrogen). The variation in the nitrogen concentration was small. The average concentration was 38 mgN $l^{-1}$ in the inflow and 29 mgN $l^{-1}$ in the outflow water. The nitrogen purification efficiency of the system was 24 %. No remarkable differences were observed between the basins. The nitrate content was low in all basins during the whole study period, not exceeding 0.2 mgN $l^{-1}$. Could the nitrate have been taken up by the plants?

The average total phosphorus content dropped from 6.3 (inflow) to 5.6 mg $l^{-1}$ (outflow). Phosphorus removal can be improved by using additional measures (lime, leca etc.) to increase the phosphorus adsorption.

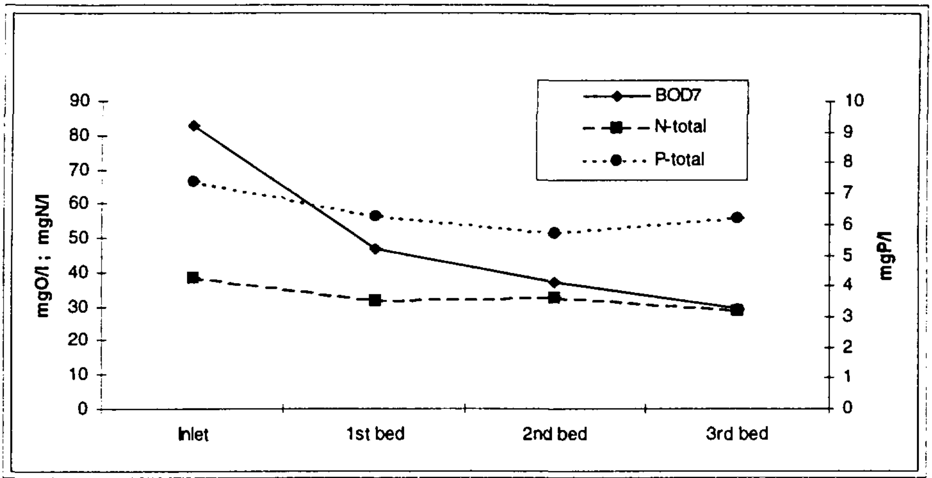


Fig. 2. Average values of $BOD_7$, total nitrogen and total phosphorus in the Aarike wastewater purification willow plantation during the study period May-October, 1995.

### *Willow production*

In the beginning of November 1995, the height of the first-year shoots exceeded 2 m in all basins, reaching 2.8 m in the first one. Preliminary production estimates demonstrate very high figures for the establishment year. The above-ground stem productivity (calculated according to Koppel 1996) of the willow was 1.6, 1.3, and 0.9 tDM $ha^{-1}$ in the first, second and third basins, respectively. The leaf production was approximately 0.42 t in the first basin. Lower growth in the second and third basins can be explained probably both by the shading effect of neighbouring high trees of the surroundings and by the nutrient gradient built up along the pathway of the wastewater flow. The production figures for the Aarike plantation in the year of establishment are three to five times higher than those for the other Estonian energy forest plantations at comparable age.

## Conclusions

The experiences and the results from the year of establishment make it possible to draw the following conclusions from the Aarike experimental willow plantation for wastewater treatment:

- The efficiency of $BOD_7$, nitrogen and phosphorus purification was 65 %, 24 % and 11 %, respectively. Outflow quality in most cases met the Estonian wastewater effluent requirements of 25 mgO $l^{-1}$ of $BOD_7$ (the average for the whole study period being 29.5 mgO $l^{-1}$).
- The above-ground production of willow stems (bark and wood) was 1.3 tDM $ha^{-1}$, which is considerably higher than the average of Estonian energy forest experimental plantations of same age.
- The willow production rate as well as the wastewater purification efficiency indicate a possibility to combine wastewater treatment with energy forest cultivation. However, for large-scale experiments, technical problems of building and maintenance of the system have to be solved.

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**References**

APHA. 1981. Standard Method for the Examination of Water and Waste Water, 15th edition, American Health Organisation Washingthon.

Aronsson, P. and Perttu, K. 1994. A complete system for wastewater treatment using vegetation filters. In: Aronsson, P. and Perttu, K. (Eds.). Willow vegetation filters for municipal wastewaters and sludges. A biological purification system. Swedish University of Agricultural Sciences Dept. of Ecol. and Env. Res., Uppsala, Sweden. Report 50:211-213.

Brix, H. 1994. Constructed wetlands for municipal wastewater treatment in Europe. In: Mitsch, W. (Ed.). Global Wetlands: Old World and New. Elsevier Amsterdam. pp. 325-334.

Geller, G. (Ed.). 1992. Bewachsene Bodenfilter zur Abwasserreinigung. Landschaftökologie Weihenstephan. 177 pp.

Guterstam, B. 1991. Ecological engineering. for wastewater treatment: Theoretical foundations and practical realities. In: Etnier, C. and Guterstam, B. (Eds.). Ecological engineering for wastewater treatment. Proc. of the International Conference at Stensund Folk College, Sweden, March 24 - 28, 1991. Bokskogen Sweden. pp. 38-54.

Hasselgren, K. 1994. Kågeröd wastewater recycling experiment. In: Aronsson, P. and Perttu, K. (Eds.). Willow vegetation filters for municipal wastewaters and sludges. A biological purification system. Swedish University of Agricultural Sciences Dept. of Ecol. And Env. Res., Uppsala, Sweden. Report 50:207.

Jenssen, D., Krogstad, T., and Mæhlum, T. 1991. In: Etnier, C. and Guterstam, B. (Eds.). Ecological engineering for wastewater treatment. Proc. of the International Conference at Stensund Folk College, Sweden, March 24 - 28, 1991. Bokskogen Sweden. pp. 227-238.

Koppel, A. 1994. Energy forests in Estonia. Situation in 1994. In: Aronsson, P. and Perttu, K. (Eds.). Willow vegetation filters for municipal wastewaters and sludges. A biological purification system. Swedish University of Agricultural Sciences, Dept. of Ecol. And Env. Res., Uppsala, Sweden. Report 50:23-26.

Koppel, A. 1996. Above-ground productivity in Estonian willow energy forests. In: Perttu, K. and Koppel, A. (Eds.). This issue.

Kutera, J., Soroko, M. 1994. The use and treatment of wastewater in willow and poplar plantations. In: Aronsson, P. and Perttu, K. (Eds.). Willow vegetation filters for municipal wastewaters and sludges. A biological purification system. Swedish University of Agricultural Sciences Dept. of Ecol. And Env Res., Uppsala, Sweden. Report 50:37-47.

Mitsch, W. and Jørgensen, S.E. 1989. Introduction to ecological engineering. In: Mitsch, W. and Jørgensen, S.E. (Eds.). Ecological Engineering: An introduction to Ecotechnology. J. Wiley and Sons, Inc., New York. pp. 3-12.

Obarska-Pempkowiak, H. 1994. Present state of the art in Poland concerning vegetation filters. In: Aronsson, P. and Perttu, K. (Eds.). Willow vegetation filters for municipal wastewaters and sludges. A biological purification system. Swedish

University of Agricultural Sciences Dept. of Ecol. And Env. Res., Uppsala, Sweden. Report 50:27-34.

Perttu, K. 1994. Wastewater treatment at Österäng, Götene using willow vegetation filters. In: Aronsson, P. and Perttu, K. (Eds.). Willow vegetation filters for municipal wastewaters and sludges. A biological purification system. Swedish University of Agricultural Sciences Dept. of Ecol. And Env. Res., Uppsala, Sweden. Report 50:209-210.

Perttu, K. and Kowalik, P.J. 1996. *Salix* Vegetation Filters for Purification of Waters and Soils. Paper presented at the IUFRO Congress in Tampere, Finland, 5-10 August 1995 and thereafter revised for journal publication. Accepted in Biomass and Bioenergy 1996.

Tchobanoglous, G. 1991. Land-based systems, constructed wetlands, and aquatic plant systems in the United States: An overview. In: Etnier, C. and Guterstam, B. (Eds.). Ecological engineering for wastewater treatment. Proc. of the International Conference at Stensund Folk College, Sweden, March 24 - 28, 1991. Bokskogen Sweden. pp. 110-120.