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Constructed wetlands with horizontal subsurface flow in the Czech Republic: Two long-term case studies

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ABSTRACT

Constructed wetlands have been used for treatment of municipal and domestic sewage in the Czech Republic since 1989. At present, nearly 250 constructed wetlands (CWs) are in operation and all CWs have been designed with horizontal sub-surface flow. The present study describes long-term treatment performance of two systems. Constructed wetland at Âitenice treats domestic sewage from 6 PE and was put in operation in 1993. Single bed with the surface area of 18 m^2 is filled with gravel (4–32 mm) and in the beginning it was planted with Common reed (*Phragmites australis*). Constructed wetland at Ļ istá was built in 1994 for 800 PE and combined sewer system. Four beds with a total surface of 3,040 m^2 are filled with crushed rock (4–12 mm) and planted with Common reed and Reed canarygrass (*Phalaris arundinacea*) The evaluation of the treatment performance presented in this paper is based on the periods 1994–2004 and 1995–2007 for Âitenice and Ļ istá, respectively. The results represent a "typical" treatment efficiency achieved in horizontal flow CWs — high removal of organics (BOD_5, COD) and suspended solids and low removal of ammonia and phosphorus. However, in both constructed wetlands BOD_5 and TSS are the primary target and therefore the design was set to meet these requirements. The system at Ļ istá is a good example of the ability of HF constructed wetlands treat wastewaters with low organic load. The results presented in this paper indicate that horizontal flow constructed wetlands are a suitable alternative for treatment of wastewater from small sources of pollution when organics and suspended solids are the primary target.

Keywords: Common reed; Constructed wetlands; Czech Republic; Sewage

1. Introduction

After a short period of experimentation in small-scale units the first full-scale constructed wetland in the Czech Republic was put in operation in 1989 [1]. The system was designed to treat runoff waters from a dung-hill but due to lack of rainwater and thus lack of runoff in summer 1989, it was decided to use the system for the treatment of sewage from the adjacent village. Despite the fact the treatment system was built with little knowledge on constructed wetlands and it was originally designed for different type of wastewater, the treatment effect was very high [2]. However, the appearance of the system, which was really far from neat, became pretence for negative opinions on constructed wetlands given by various organizations (hygiene service, water inspection, the Ministry of the Environment, etc.). Unfortunately, the results themselves were not taken into consideration and, as a result, in 1990 none and in 1991 only four constructed wetland for wastewater treatment were built and put in full operation.

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Since 1992 a steep increase in a number of constructed wetlands has occurred. The major factor influencing this phenomenon was the cancellation of "Recommended list of treatment systems for small point sources of pollution" at the end of 1991. This list offered various technologies (e.g. oxidation ditch, rotating biological contactors or simple activated sludge technologies) but did not include constructed wetlands (however, it did include soil filtration). By the end of 2007 about 250 constructed wetlands have been put in operation. All the constructed wetlands have been designed with horizontal subsurface flow and were continuously reviewed by Vymazal [2–6].

Most constructed wetlands were designed to treat municipal or domestic sewage; other uses include stormwater runoff, dairy, abattoir, bakery and goat farm [6]. The size varies from small systems for single houses (<10 PE) to 1,400 PE. Most systems have been designed as on-site systems or between 100 and 500 PE. Most frequently used filtration media are washed gravel and crushed stones with fractions 4–8 and 8–16 mm. *Phragmites australis* is the most frequently used plant in the Czech Republic. It is used either as a single species or in combination with other species, such as *Phalaris arundinacea* [7].

The objective of this study was to evaluate long-term treatment performance of constructed wetlands Čistá and Žitenice which were built in 1993 and 1994, respectively.

Fig. 1. Constructed wetland Žitenice. Top — general view, bottom — detail. Photo by author.

Fig. 2. Constructed wetlands Čistá. Photo by author.

2. Materials and methods

Constructed wetland Žitenice was built in 1993. It consists of septic tank and a single 18 m^2 bed filled with gravel (3–15 mm) and planted with Common reed (*Phragmites australis*). In 2002, the part of the bed was replanted with Yellow flag (*Iris pseudacorus*) in order to create more decorative cover (Fig. 1). It serves 6 PE and the average measured flow over the monitored period was 0.60 m^3 d^{-1}. Constructed wetland in Čistá (Fig. 2) was built in 1995 for 800 PE. It consists of Imhoff tank and four beds (760 m^2 each) filled with gravel (8–12 mm) and planted with *P. australis* and Reed canarygrass (*Phalaris arundinacea*) planted in bands perpendicular to water flow. The average flow over the monitored period was 310 m^3 d^{-1} which indicates high rate of dilution with stormwater runoff.

Both constructed wetlands were regularly sampled for BOD$_5$, COD and TSS on a quarterly basis. At Žitenice, the samples were taken bimonthly during the period 2002–2003. At Žitenice, only outflow concentrations were recorded during the period 1998–2001 and therefore these results are not included in the study. Nutrients were recorded irregularly because these values are not limited in the discharge and available data were obtained only during the research projects. The sampling points were at the inflow of raw sewage and at the final discharge from vegetated beds.

3. Results and discussion

3.1. Constructed wetland Žitenice

In Table 1, treatment performance of the system at Žitenice is shown. This constructed wetland represents a typical single house on-site treatment situation with high inflow concentrations of organics, suspended solids and nutrients. The results indicate that removal of organics and suspended solids was excellent with average removal values amounting to 95.4%, 91.2% and 97.3% for BOD$_5$, COD and TSS, respectively. The average or-

Table 1
Removal of organics (BOD_5, COD) and suspended solids (TSS) in constructed wetland Žitenice during the period 1994–2004. Values in mg l^{-1}, standard deviations in parentheses

	BOD_5 in	BOD_5 out	COD in	COD out	TSS in	TSS out
1994	271 (166)	40 (22)	642 (194)	169 (94)	137 (52)	18.8 (6.9)
1995	336 (35)	15 (6.6)	618 (59)	87 (54)	154 (82)	18.7 (15)
1996	333 (33)	12.5 (8.0)	767 (120)	102 (97)	258 (32)	8.0 (5.0)
1997	129 (20)	11 (1.0)	240 (45)	60 (5.0)	266 (41)	6.0 (4.5)
2002	383 (210)	4.8 (4.2)	1202 (959)	27 (4.8)	695 (723)	5.5 (3.5)
2003	314 (160)	12 (6.8)	946 (525)	38 (10)	491 (346)	6.8 (3.4)
2004	486 (242)	7.7 (1.8)	1461 (642)	38 (6.0)	839 (497)	13.1 (7.0)
Mean	322 (100)	14.7 (10.8)	839 (374)	74 (46)	406 (255)	11.0 (5.4)

Table 2
Removal of nutrients in constructed wetland Žitenice during the period 1994–2004. Values in mg l^{-1}, standard deviations in parentheses

	TP in	TP out	NH_4-N in	NH_4-N out	TN in	TN out
2002	14.9 (15.1)	4.0 (1.3)	38.1 (13.9)	20 (10.7)		
2003	17.7 (7.9)	8.7 (1.7)	63 (22.1)	45 (6.0)	84 (30.4)	48 (7.6)
2004	17.6 (5.3)	12.7 (2.1)	54 (7.5)	57 (5.2)	86 (17.5)	62 (6.0)
Mean	16.7 (1.3)	8.5 3.6)	52 (10.3)	41 15.5)	85 (1.0)	55 (7.0)

ganic loading (calculated for raw sewage) during the monitored period was 10.7 g BOD_5 m^{-2} d^{-1} resulting in a specific area of 5.6 m^2 PE^{-1}. The given specific area is commonly used to design horizontal flow constructed wetlands in order to achieve high removal of organics [8–10].

Removal of nutrients is shown in Table 2. Average removal of phosphorus amounted to 49.1%. This is very common result for horizontal sub-surface flow constructed wetlands where ordinary filtration materials (in this case gravel) are used. It has been well established that for high phosphorus removal special materials with high sorption capacity must be used such as light weight aggregates [11,12], blast and electric arc furnaces steel slags [13–15] or fly ash [16]. Removal of ammonia-N is very low (21.1%) but typical for this type of constructed wetlands. The major reason for low ammonia-N removal is the lack of oxygen in filtration bed and subsequent low nitrification [8]. Elimination of ammonia-N is actually higher as organic nitrogen is mineralized to ammonia in the wetland. In Žitenice, removal of organic nitrogen was very high — the inflow concentrations of 19.3 and 32.2 mg l^{-1} were reduced to 1.6 and 0.5 mg l^{-1} in 2003 and 2004, respectively. Ammonification, i.e. degradation of nitrogen-containing organic compounds proceeds both under aerobic and anaerobic conditions [17]. The removal of total nitrogen is therefore higher (35.3%) and well within the range commonly found in this constructed wetland type [17].

3.2. Constructed wetland Čistá

This system is an example of a constructed wetland treating municipal combined sewer wastewater which is quite common in the Czech Republic [6]. Removal of BOD_5 of constructed wetland Čistá during the period 1995–2007 is documented in Figs. 3 and 4. The high dilution is evident from low inflow concentrations. However, the results indicate the fact that constructed wetlands can successfully treat diluted wastewater with low content of organic matter, in the situation where the use of conventional treatment systems such as activated sludge process is difficult and unreliable. Activated sludge treatment process needs at least 50–80 mg l^{-1} BOD_5 in order to keep the healthy biocenosis of activated sludge. The data shown in Fig. 4 also reveal that despite high fluctuations in inflow water quality, the outflow BOD_5 concentrations are quite steady and do not fluctuate. During the monitored period, i.e. more than 12 years, the outflow concentrations varied only between 1.5 and 18 mg l^{-1} with the average value of 6.7 mg l^{-1} while the inflow concentrations varied between 6.3 and 270 mg l^{-1}. Also, average outflow COD (Fig. 5) and TSS (Fig. 6) concentrations varied only slightly from 23 to 54 mg l^{-1} and

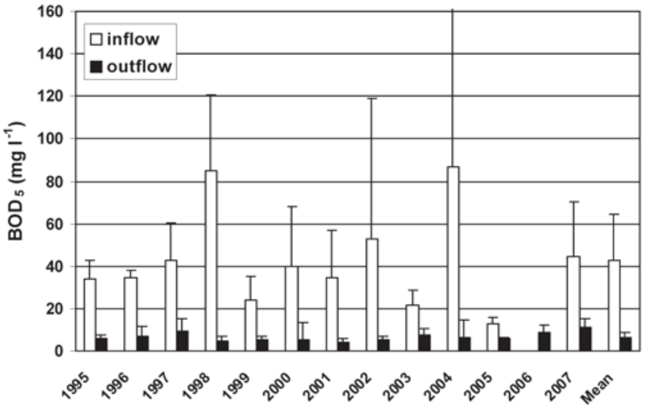

Fig. 3. Average inflow and outflow BOD_5 concentrations during the period 1995–2007 in constructed wetland Čistá.

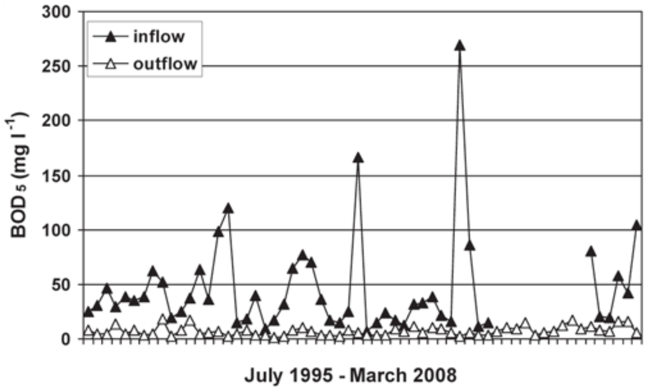

Fig. 4. Removal of BOD_5 in constructed wetland Čistá during the period 1995–2007.

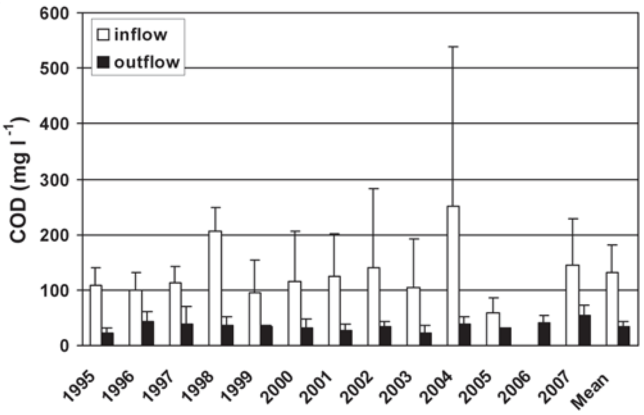

Fig. 5. Average inflow and outflow COD concentrations during the period 1995–2007 in constructed wetland Čistá.

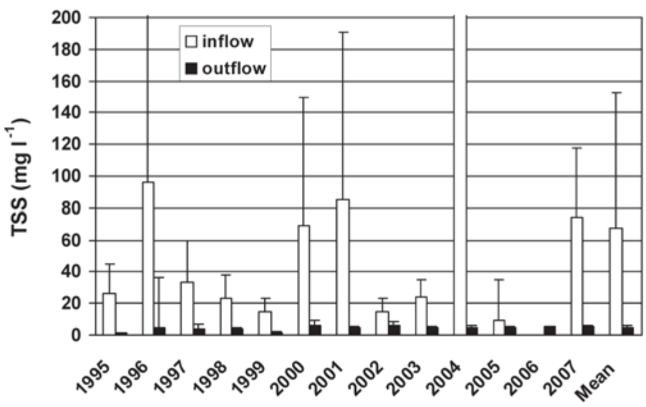

Fig. 6. Average inflow and outflow TSS concentrations during the period 1995–2007 in constructed wetland Čistá.

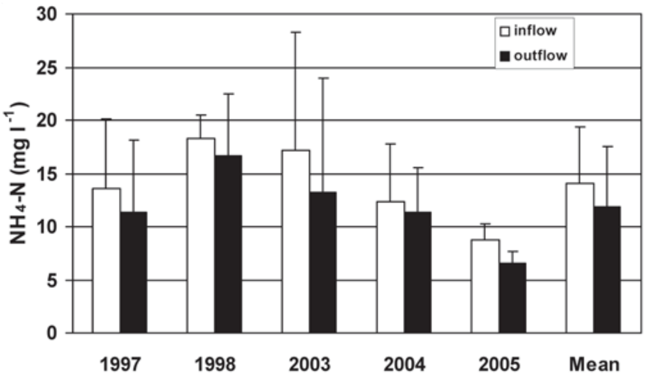

Fig. 7. Average inflow and outflow NH_4-N concentrations during 1997, 1998 and the period 2003–2005 in constructed wetland Čistá.

from 1.3 to 6 mg l^{-1}, respectively. Removal of ammonia-N was low (Fig. 7) as can be expected for this type of constructed wetlands.

Treatment effect expressed as percentage removal is lower than in Žitenice — 86.4%, 74.8%, 94% and 16.3% for BOD_5, COD, TSS and NH_4-N, respectively. However, these values are strongly affected by low inflow concentrations but outflow concentrations are much lower as compared to Žitenice. This clearly shows that to evaluate the treatment efficiency only on the basis of percentage could be very misleading. The average inflow organic load (calculated for raw sewage) was 4.3 g BOD_5 m^{-2} d^{-1} resulting in a specific area of 14 m^2 PE^{-1}.

4. Conclusions

Constructed wetlands at Žitenice and Čistá proved that constructed wetlands with horizontal subsurface flow are suitable solutions for treatment of wastewaters when organics and suspended solids are the primary target. The long-term data indicate that horizontal flow constructed wetlands can handle successfully wastewaters diluted with stormwater runoff as well as very strong domestic wastewaters. Removal of nutrients is low in both systems but this is typical for this type of constructed wetlands.

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