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Long term treatment performance of constructed wetlands for wastewater treatment in mountain areas: Four case studies from the Czech Republic

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ABSTRACT

Four constructed wetlands with horizontal subsurface flow situated 500 m a.s.l. were surveyed in order to evaluate long-term treatment efficiency. The results revealed that treatment performance of all surveyed constructed wetlands is excellent for organics and suspended solids and varied between 88% and 94% for BOD_5, 67% and 85% for COD and 74% and 96% for TSS. Removal of NH_4^+-N in CWs Zásada has improved over the time of operation and average treatment efficiency amounted to 53%. There was no difference between summer and winter NH_4-N outflow concentrations. Average removal of TP amounted to 59% and the removal efficiency was very stable over the 18 years of operation.

1. Introduction

Constructed wetlands have been used for wastewater treatment for more than four decades (Vymazal, 2011a). The early studies based on theoretical bases suggested that constructed wetland technology would not be suitable for higher altitude locations due to inability of commonly used plants to survive harsh conditions connected with sub-mountainous and mountainous regions and because of filtration bed freezing. However, the field experience has indicated that plants can grow well and filtration bed does not freeze in high altitude locations (Navara, 1996; Merlin et al., 2002; Züst and Schönborn, 2003). This fact was also observed under northern latitude conditions such as in USA (Minnesota, Vermont, California), Norway, Canada or Northern Japan (e.g., Reuter et al., 1992; Kadlec et al., 2003; Mander and Jenssen, 2003; Muñoz et al., 2006; Giæver, 2003; McCarey et al., 2004; Yates et al., 2012; Kato et al., 2013).

There are several factors which make possible constructed wetlands with horizontal sub-surface flow to perform efficiently under cold climatic conditions in high altitude locations. It has been well established that plant biomass including plant litter provides good insulation during the periods of cold weather (Hiley, 2003; Vymazal and Kröpfelová, 2008; Vymazal, 2011b). Also, at cold temperatures the amount of oxygen that can dissolve in water is greatly increased (Hiley, 2003). One of the positive functions that macrophytes play in CWs with horizontal sub-surface flow is the release of oxygen from roots and rhizomes into the rhizosphere (Brix, 1987, 1997; Vymazal, 2011c). Root and rhizome respiration declines with decreasing temperature and therefore, the amount of released oxygen may increase during cold periods (Callaway and King, 1996). Hook et al. (2003) reported that the cold period performance is also affected by the biomass and structure of belowground parts of plants. In their experiments, *Carex rostrata* was superior to *Typha latifolia* and *Scirpus acutus* in COD removal. The authors attributed better *Carex* performance to higher belowground biomass and the fact that roots grow in fall and winter and belowground biomass reaches its annual maximum in winter (Bernard, 1974; Aerts and de Calluwe, 1995).

The objectives of this study was to evaluate treatment performance of four constructed wetlands with horizontal sub-surface flow built in the period 1993–1998 located in sub-mountainous and mountainous regions in the Czech Republic. The survey was carried out in 2013 taking into consideration available results obtained by 2012 with the exception of CW Zásada, where 2013 was included as well.

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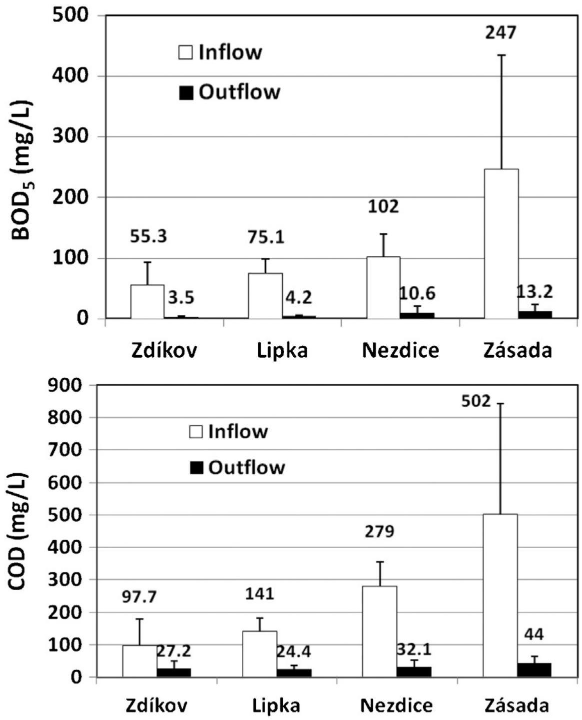

Fig. 1. Average inflow and outflow BOD_5 and COD concentrations in all monitored constructed wetlands. Data from the periods 1998–2012 (Zdíkov), 1997–2012 (Lipka), 2000–2012 (Nezdice) and 1995–2013 (Zásada).

2. Materials and methods

In the Czech Republic the first full scale constructed wetland for wastewater treatment was built only in 1991 (Vymazal, 1993). At present, about 300 constructed wetlands (CWs) are in operation. All CWs in the Czech Republic are designed with horizontal subsurface flow (HF CWs) (Vymazal, 2011b), while vertical flow (VF) CWs are still in the experimental stage (Vymazal and Kröpfelová, 2011; Hudcová et al., 2013). For the purpose of this study we selected four constructed wetlands which are situated at altitude 500 m a.s.l. Indeed, there are more CWs located in mountainous areas but available data from those systems are to be considered insufficient. The basic design parameters of surveyed constructed wetlands are shown in Table 1. The pretreatment in all systems consists of screens, horizontal grit chamber and Imhoff tank. All the systems have been in operation for at least 15 years during the time of the survey with the oldest system being in operation for 20 years.

All the systems were designed according to European Guidelines (Cooper, 1990) and the required area was calculated according the following formula:

$$A = \frac{Q(\ln C_i - \ln C_o)}{k_A},$$

where

A = area of the bed (m^2)
C_o = outflow concentration ($mg\,l^{-1}$)
C_i = inflow concentration ($mg\,l^{-1}$)
k_A = first-order areal rate constant ($m\,d^{-1}$)

The surveyed constructed wetlands were designed according to the BOD_5 removal with the value of $K_{A(BSK)}$ of 0.1 $m\,d^{-1}$. This approach is more or less used even nowadays. None of the surveyed

Table 1
Major design parameters of monitored constructed wetlands.

CW	Elevation (m a.s.l.)[a]	T (°C)[b]	Built	Surface area (m^2)	No. of bed	PE[c]	Filter material	Size (mm)	Vegetation[d]	Type of sewer	Flow[e] ($m^3\,d^{-1}$)	HLR[f] ($cm\,d^{-1}$)	Evaluated period
Zdíkov	862	4.3	1995	750	2	150 (115)	Gravel	4/8	*Phragmites*	Combined	21.9	2.9	1998–2012
Lipka	850	4.7	1993	1890	2	300 (75)	Gravel	4/8	*Phragmites*	Combined	41.3	2.2	1997–2012
Nezdice	610	7.3	1998	2100	2	450 (500)	Gravel	4/16	*Phragmites* *Phalaris*	Combined	55.4	2.6	2000–2012
Zásada	520	6.1	1995	2020	2	400 (420)	Gravel	8/16	*Phalaris*	Separate	47.6	2.4	1995–2012
			2008[g]	3500	3	620 (615)			*Phalaris*		70.2	2.0	

[a] Above the sea level.
[b] Average annual temperature for the period 1961–2011.
[c] PE = population equivalent, the numbers denote designed PE with number of people connected in 2013 in parentheses, in Zásada, the first number in parentheses is for 2004.
[d] *Phragmites* = *Phragmites australis*, *Phalaris* = *Phalaris arundinaces*.
[e] Average flow for the whole period of operation.
[f] LR = hydraulic loading rate.
[g] in 2008, the constructed wetland was extended.