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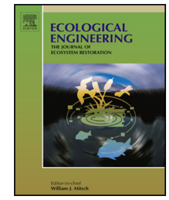

Short communication

Modelling of vertical subsurface flow constructed wetlands for treatment of domestic sewage and stormwater runoff by subwet 2.0

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A B S T R A C T

With the increasing number of constructed wetlands being built, the modelling of wetland function and performance is valuable. This work examines the efficacy of applying a numeric model (SubWet 2.0) originally designed for horizontal subsurface flow wetlands to model wastewater treatment within vertical subsurface flow constructed wetlands (VSSF-CWs). The treatment efficiencies of two VSSF-CWs with substantially different influent characteristics, one in Canada and one in China, were modelled with SubWet 2.0 and simulated values were then compared to observed values to determine how closely SubWet 2.0 reflects the actual observed performance of these wetlands. The model was calibrated to each wetland with observed data that had been collected prior to the simulations. The correlation coefficient (*R*) and Nash–Sutcliff coefficient of efficiency (NSE) were used to evaluate the modelling performance for 5-day biochemical oxygen demand (BOD_5), ammonium nitrogen, nitrate nitrogen and total phosphorous (TP). The results showed that the modelling performance for TP and BOD_5 was better for these parameters than that observed for ammonium nitrogen and nitrate nitrogen for either of the two wetlands. For TP and BOD_5, the correlation coefficient *R* achieved a value of 0.79 for the wetland receiving stormwater and exceeded this value for the Canadian wetland receiving domestic wastewaters. For nitrate nitrogen, the wetland treating domestic waste showed a correlation coefficient *R* as high as 0.97, while the wetland treating stormwater runoff had a correlation coefficient *R* of 0.48. For ammonium nitrogen, both wetlands showed low correlation coefficients with values of 0.70 and 0.60 for domestic wastewater and for stormwater runoff, respectively. This study demonstrated that SubWet 2.0 is suitable for the modelling of VSSF-CWs. The two case studies, with substantial differences in the characteristcs of the influents, demonstrated that Subwet 2.0 is a versatile and robust tool for modelling of constructed wetlands.

1. Introduction

A constructed wetland (CW) is an alternative engineered process commonly used for treating contaminated water. CWs embody treatment processes analogous to those found in natural wetlands; including physical, chemical and biological processes, such as sedimentation, filtration, precipitation, sorption, plant uptake, microbial decomposition and nitrogen transformations (Dan et al., 2011; Faulwetter et al., 2009; Liang et al., 2009).

With the increasing number of CWs being built, the modelling of wetland function and performance has also attracted more attention. The main objectives of these modelling studies are to better understand the treatment processes in CWs and to improve the design, management, monitoring and maintenance of CWs. The SubWet 2.0 model is an interesting option that was originally developed for HSSF wetlands. This model has been reviewed and described previously by Jørgensen and Gromiec (2011); Chouinard et al. (2014a,b); Chouinard et al. (2014a,b). A key feature of SubWet 2.0 is the relative ease in calibrating the model to site conditions. This is done by adjusting the rate coefficients (within a defined range) until simulated values match observed values. In this manner, SubWet provides an integrated process response which lessens the need to know specific details about all treatment

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Table 1
Characteristics of the influents for VFCW^{I} and VFCW^{II}.

Contents	Observed influents										
	Unit	Mean		Standard deviation		Median		Maximum		Minimum	
	–	VFCW^{I}	VFCW^{II}	VFCW^{I}	VFCW^{II}	VFCW^{I}	VFCW^{II}	VFCW^{I}	VFCW^{I}	VFCW^{I}	VFCW^{II}
BOD_5	mg/L	15.3	11.5	6.4	4.0	16.5	11.0	32.0	21.8	3.0	4.0
COD	mg/L	45.1	38.3	17.4	13.2	48.1	36.7	79.1	72.6	21.5	13.3
Ammonia nitrogen	mg/L	12.9	3.0	14.9	2.0	9.3	2.3	62	7.6	1.1	0.5
Nitrate nitrogen	mg/L	12.0	0.11	18.2	0.1	3.8	0.2	69	0.6	0.2	0.1
TN	mg/L	22.6	11.3	20.9	6.9	15.7	9.7	76.1	29.6	2.6	3.7
TP	mg/L	11.1	0.13	3.8	0.06	9.8	0.11	23.2	0.31	7.0	0.05

DO 3.6–8.8, Temp. 9.2–20 °C, pH 7.49–7.91 in VFCW^{I}.
DO 1.5–5.0, Temp. 4.5–22.4 °C, pH 7.59–8.11 in VFCW^{II}.

processes. For example, the ability to calibrate to site conditions allowed SubWet to be successfully applied to natural tundra treatment wetlands, where several of the parameters such as hydraulic loading and bed depth were variable and poorly defined (Chouinard et al., 2014b).

The goal of this study was to assess the efficacy of SubWet 2.0 being applied to a vertical subsurface flow constructed wetland (VSSF-CW) in the hope that this model would provide a user-friendly, low cost and reasonably accurate option for the modelling of VSSF-CWs. For this purpose the performance of SubWet 2.0 was assessed by calibrating it to two different VSSF-CWs that treated different sources of wastewaters. One of the VSSF-CWs was located in south eastern Canada and treated domestic wastewater, while the other CW was located in China and treated stormwater runoff.

2. Methodology and materials

2.1. Case studies

The present study investigated two VSSF-CWs in two locations; one in Canada and one in China. The VSSF-CW^{I} (as CW^{I}) system was built at the Centre for Alternative Wastewater Treatment in Canada (latitude 45.05°, and longitude 78.53°) to treat domestic sewage. The size of the vertical flow wetland cell was 4.0 m in length, 3.0 m in width and 1.5 m deep. The main matrix of the vertical flow wetland cell was sand. The treatment volume was between 15.5 and 16.6 m^3 of waste water per day. The porosity of the matrix was estimated to be 0.35 and the effective volume of the vertical flow wetland bed was 6.3 m^3 (in winter, the influent level was decreased to prevent surface freezing which reduced the effective volume of the wetland bed to 3.15 m^3). *Phragmites spp.* was planted in the vertical flow wetland cell.

The VSSF-CW^{II} (as CW^{II}) was built at Tianjin University in China (latitude 39.11°, and longitude 117.17°) to treat the water from a nearby stormwater pond. The dimensions of the vertical wetland flow wetland cell were 1.0 m in length, 0.5 m in width and 0.9 m deep. The matrix of the wetland cell consisted of gravel and ceramsite. The system was designed to treat a volume of 0.8–2.7 m^3 of stormwater runoff per day. The porosity of the matrix was estimated to be 0.87 and the effective volume of the wetland bed was 0.39 m^3. There were no plants in this system.

2.2. Data

Water quality monitoring data were collected at the influent and effluent of CW^{I} from February to September of 2013 and the CW^{II} from June to December of 2013. Water samples were analysed for biochemical oxygen demand (BOD_5, mg/L), chemical oxygen demand (COD, mg/L), nitrite nitrogen (mg/L), nitrate nitrogen (mg/L), ammonium nitrogen (mg/L), total Kjeldahl nitrogen (TKN, mg/L), total nitrogen (TN, mg/L), dissolved oxygen (DO, mg/L), phosphate as PO_4 (mg/L), total phosphorus as P (TP, mg/L), pH and temperature (°C) according to standard methods (APHA, 2005).

Table 1 summarizes the characteristics of the influents for the main parameters including BOD_5, COD, nitrate nitrogen, ammonium nitrogen, TN and TP. The mean and standard deviation of the influent concentrations of CW^{I} are higher than CW^{II} since the source wastewater was pre-treated (septic tank) domestic sewage, while the influent of CW^{II} was stormwater runoff. The mean values of nitrate nitrogen and TP of CW^{I} were more than 100× the values of CW^{II}, while the standard deviations of nitrate nitrogen and TP of CW^{I} were 63× and 180× the values of CW^{II}, respectively. The mean values of TN and ammonium nitrogen for CW^{I} were 2× and 4.3× the values of CW^{II}, while the standard deviations of TN and ammonium nitrogen of CW^{I} were 3.0× and 7.5× the values of CW^{II}, respectively. BOD_5 and COD were approximately the same for the two CWs.

2.3. Model description (SubWet 2.0)

SubWet was developed by UNEP-DTIE-IETC, and was originally intended for use in the design of horizontal subsurface flow constructed wetlands for the treament of domestic wastewaters. The model employs 25 differential process equations and 16 parameters as described by Jorgensen and Fath (2011). It can simulate the removal of BOD_5, nitrate nitrogen, ammonium nitrogen, organic nitrogen and TP in milligrams per liter and the corresponding removal efficiencies in percentage.

2.4. Modelling setup

Cold climate wetlands are defined in SubWet 2.0 as being sites with surface temperatures varying between below freezing in

Table 2
The correlation between observed and simulated results in VFCW^{I} and VFCW^{II}.

Variable (mg/L)	Correlation coefficient (*R*)		NSE		*P* value	
	VFCW^{I}	VFCW^{II}	VFCW^{I}	VFCW^{II}	VFCW^{I}	VFCW^{II}
BOD_5	0.84	0.79	0.53	0.26	<0.0001	<0.0001
Ammonia-nitrogen	0.70	0.60	0.51	0.33	0.002	0.001
Nitrate- nitrogen	0.97	0.48	0.93	0.23	<0.0001	0.012
TP	0.94	0.98	0.87	0.94	<0.0001	<0.0001