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Comparative Analysis of Greenhouse Gas Emission from Three Types of Constructed Wetlands

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Wastewater treatment processes can produce anthropogenic greenhouse gases, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Wastewater treatment in the U.S. emitted 17.8 Tg CO_2equivalent (CO_2-eq) in 2012, accounting for 0.27% of the U.S. total greenhouse gas emission and 14.3% of the total greenhouse gas emission from waste management and treatment activities (U.S. EPA, 2014). Constructed wetlands are green infrastructure for treatment of various types of wastewater. As ecologically engineered treatment systems, constructed wetlands mimic the appearance of natural wetlands (Figure 1). Constructed wetlands utilize natural processes involving macrophytes, soils or other porous media, and the associated microbial assemblages for water quality improvement. There are mainly three types of constructed wetlands [1]. Free water surface (FWS) wetlands typically consist of cells with aquatic plants, relatively impermeable rooting substrate, and shallow water. Treatment in FWS constructed wetlands occurs as water flows slowly above ground through the leaves and stems of aquatic plants. Horizontal subsurface flow (HSSF) wetlands contain beds of porous media that may have been planted with aquatic plants. Wastewater flows horizontally beneath the surface of the medium beds. Vertical flow (VF) wetlands contain beds of media that may have been planted with aquatic plants. Water is distributed over the ground surface or from the base, and flows downward or upward through the medium beds.

When designing a constructed wetland treatment system, wetland type is first selected in regards to several factors such as land availability, local climate, and wastewater characteristics. Sustainability has become an important consideration in wastewater treatment. Correspondingly, greenhouse gas emission from constructed wetlands has been measured in full-scale constructed wetlands in the last decade. Mander et al. [2] compared the three types of constructed wetlands in terms of CO_2-C, CH_4-C, and N_2O-Nemission rates separately. Actually, the same mass emission rates of CO_2, CH_4, and N_2O contribute very differently to global warming. To compare the overall effect of greenhouse gas emissions amongst different types of constructed wetlands, it is necessary to calculate CO_2-eq emissions [3,4]. With inclusion of climate-carbon feedbacks in response to emissions of non-CO_2 gases, the 100-year global warming potential (GWP_{100}) is 1 for CO_2, 34 for CH_4, and 268 for N_2O (IPCC, 2013). CO_2-eq emission rate in the three types of constructed wetlands were then obtained by multiplying the emission rate of a greenhouse gas reviewed by (2) by its GWP_{100} as given in Equations 1-3:

$$CO_2\text{-eq of } CO_2,\ mg/m^2/h=(CO_2,\ mg\ C/m^2/h) \times (44/12) \times 1 \quad (1)$$

$$CO_2\text{-eq of } CH_4,\ mg/m^2/h=(CH_4,\ mg\ C/m^2/h) \times (16/12) \times 34 \quad (2)$$

$$CO_2\text{-eq of } N_2O,\ mg/m^2/h=(N_2O,\ mg\ N/m^2/h) \times (44/28) \times 268 \quad (3)$$

Based on emission rates of individual greenhouse gases, Mander et al., [2] concluded that CO_2 emission was significantly lower in FWS constructed wetlands than in HSSF and VF constructed wetlands, CH_4emission was significantly lower in VF constructed wetlands than HSSF constructed wetlands, and that there were no significant differences in N_2O emission in various wetland types. Based on the CO_2-eq emission rates (Table 1), we found that:

1. CO_2-eq emission rate in constructed wetlands is in the order of HSSF>VF>FWS, either in terms of total or individual greenhouse gases except for CH_4 that FWS>VF;
2. CO_2-eq emitted from constructed wetlands is in the order of CO_2>CH_4>N_2O for all the three types of constructed wetlands.
3. CO_2 accounted for 76% of the total CO_2-eq emitted from VF constructed wetlands;
4. Both CO_2 and CH_4 are the primary greenhouse gases emitted from FWS constructed wetlands; and
5. CO_2 and CH_4 accounted for 51% and 41% of total CO_2-eq emitted, respectively, from HSSF constructed wetlands.

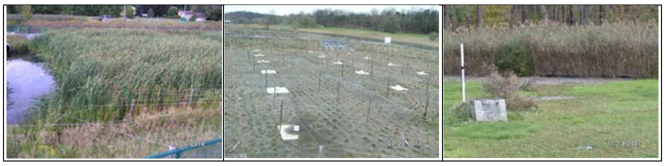

Figure 1: Appearance of full-scale constructed wetlands: a FWS wetland with well-established vegetation (left), a newly planted VF wetland with risers on concrete distribution pads (middle), and a HSSF wetland with planted and unplanted zones (right).

	FWS wetland		HSSF wetland		VF wetland	
	Average	Range	Average	Range	Average	Range
BOD loading, mg/m²/h	109	18.3-465	300	123-430	514	347-681
TOC loading, mg/m²/h	50.2	1.0-232	91.1	8.2-313	488	17.9-1418
CO_2 emission, mg CO_2-eq/m²/h	338	108-645	693	153-2079	614	466-763
CH_4 emission, mg CO_2-eq/m²/h	268	6.8-1224	336	2.2-793	132	14-245
N_2O emission, mg CO_2-eq/m²/h	55	0-274	101	0-377	59	1.3-179
Total emission, mg CO_2-eq/m²/h	661		1130		805	

[a]. Calculated with data reported by [2].

Table 1: Greenhouse gas emission in three types of constructed wetlands[a].

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To reduce greenhouse gas emission from constructed wetlands, therefore, the efforts should be focused on CO_2 and CH_4 reduction rather than N_2O which is produced in biological nitrogen removal processes including nitrification and denitrification. Biological removal of oxygen-demanding substances releases CO_2 and CH_4, with more CH_4 produced under anaerobic conditions [4]. The larger CO_2 and CH_4 emission rates in HSSF than FWS constructed wetlands could be attributed to the higher biochemical oxygen demand (BOD) and total organic carbon (TOC) loading rates (Table 1). Although VF constructed wetlands have greater BOD and TOC loading rates than HSSF constructed wetlands, CH_4 emission rate isobviously lower than HSSF constructed wetlands because VF constructed wetlands are designed typically for aerobic removal of organic carbon and ammonium. The slightly lower CO_2 emission rate in VF than HSSF constructed wetlands could be attributed to the downward flow of effluent that absorbs and carries CO_2 out.

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