Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2018.21817

101 (2018) 108–115
January

Formulation of design guidelines for the cost-effectiveness of constructed wetlands in improving water quality

Jiyeon Choi[a], Franz Kevin F. Geronimo[b], Baekyung Park[a], Jungsun Hong[b], Lee-Hyung Kim[b,*]

[a]*Water Environment Research Department, National Institute of Environmental Research, Hwangyeong-ro 42, Seo-gu, Incheon, 404-708, Republic of Korea*
[b]*Department of Civil and Environmental Engineering, Kongju National University, 1223-24, Cheonan-daero, Seobuk-gu, Cheonan, Chungnamdo, 31080, Republic of Korea, Tel. +82 41 521 9312, email: leehyung@kongju.ac.kr (L.-H.Kim)*

Received 1 December 2016; Accepted 2 November 2017

ABSTRACT

Constructed wetlands (CWs) are artificially engineered ecosystems designed and developed to manipulate the biological processes within a semi-controlled natural environment. CWs were beneficial for having uncomplicated operation and maintenance activities, providing a wildlife habitat in urban and suburban areas and an aesthetic value within the local environment. However, there were current limitations on the CWs operations such as few design guidelines, limited performance results regarding the pollutant attenuation and the absence of long-term comprehensive mass balance analysis. The objective of this research was to analyze the reduction performance of various CWs with regard to the respective monitoring data and develop the necessary design guidelines based on the similar trends analyzed from the mentioned CWs. The formulated design guideline would be suitable for CWs treating various wastewaters. In order to develop the design guideline, various CWs in Korea and other countries were investigated with respect to three scenarios namely site survey, water quality and ecosystem monitoring and performance reports. Based on the results, using the CW design characteristics (i.e., surface area, catchment area, etc.) and pollutant reduction capabilities (i.e., pollutant removal efficiency, HRT, vegetation coverage, etc.) the derivation of the formula needed to calculate the appropriate CW size, forebay size, vegetation coverage was developed. For the cost-effectiveness of the CW, the economic feasibility of the investigated CWs was evaluated with respect to the CW formation costs and was compared with the particulate removal efficiency.

Keywords: Constructed wetland; Cost-effective; Design guideline; Water quality

1. Introduction

Constructed wetlands (CWs) are artificially engineered ecosystems designed and constructed to manipulate biological processes within a semi-controlled natural environment [1–3]. Particularly, CWs facilitated a number of abiotic and biotic processes integral to wetland vegetation ecology, soil, and associated microbial assemblages assist in contaminant removal [4]. CWs were also known as treatment wetlands bridge the gap between hard engineering and natural science considering ecological technologies [5].

In Germany, the possibility of wastewater treatment through wetland plants was studied in 1950s while the root zone method was created in 1960s [2]. Researches about CWs have evolved from the treatment of municipal, industrial, greywater and stormwater runoff to more ecological and environmental applications including habitat restoration for native and migratory wildlife, land reclamation following mining, refineries, and mitigation succeeding ecological disturbances, such as wetland loss due to land development projects [4,6].

* Corresponding author.

CWs have been accepted as an attractive and economical alternative to a variety of pollution controls, including domestic wastewater [7], agricultural wastewater [8], industrial wastewater [9], urban runoff water [10] and acid mine drainage [11]. Furthermore, CWs have received increasing attention and popularity from international scientists and engineers due to the economic and ecological benefits of these wetlands. First, compared with conventional energy-intensive treatment technologies (physical–chemical–biological treatments), CWs have been shown as an attractive and stable alternative due to low costs and energy savings [12]. Second, CWs provide potentially valuable wildlife habitat in urban and suburban areas [13], as well as an aesthetic value within the local natural environment. Finally, CWs can be beneficial in small to medium sized towns due to easy operation and maintenance, providing a useful complement to traditional sewage systems, which are used predominantly in large cities [6].

Available design guidelines and methods at present were mostly based on empirical rules of thumb and simple first-order decay models [3]. However, the CW is considered to be a complex bioreactor. A number of physical, chemical and biological processes with microbial communities, emergent plants, soil and sediments accumulated in the lower layer take place in the systems. There are still many unknown parts related to CWs performance, diverse driving operations [14].

Furthermore, little design guidance for CWs is currently available, and there is an absence of comprehensive long-term mass balance data on existing systems. Nevertheless, there is a growing body of limited-scope performance data on individually constructed wetlands, from which general inferences regarding the pollutant attenuation capabilities of these systems may be drawn [15]. And little information has been presented to confirm their adequacy for attaining desired pollutant removals.

Therefore, the objective of this paper is to analyze the available information of the performance of CWs such as site survey, monitoring and literature reviews which have been used in treating various influent and in identifying cost-effective design criteria of a forebay and plant coverage rate.

2. Materials and methods

To prepare the CW design and maintenances guideline, literature study about the installation status, efficiency, and operation and management were conducted in addition to the site survey performed at 13 CWs in Korea and 40 CWs in other countries. The literature studied CWs included 38 free-water surface (FWS) CWs, 9 horizontal subsurface flow, 5 hybrid CWs and 1 vertical flow CWs as shown in Table 1. The literature study was performed with respect to the CW type, catchment area, CW area, pollutant reduction efficiency, forebay characteristics, vegetation status and coverage, and residual time.

3. Results and discussion

3.1. Cost-effective design criteria of wetland size

To maintain cost-effective multiple functions of a CW, appropriate CW size, appropriate forebay size and appropriate vegetation coverage should be taken into account during the CW design. On the basis of the monitoring results and the literature study, this section provides guidelines with respect to CW size depending on pollutant removal efficiency, method of calculating forebay size according to total suspended solids (TSS) removal efficiency, appropriate vegetation coverage depending on nutrient removal efficiency, and the relationship between removal efficiency and installation cost.

Generally recommended CW size is 2%–4% of the catchment area [39]. However, determining the CW size and block without considering the land use and influent characteristics makes CW formation difficult due to the space limit and causes problems such as decreased efficiency and difficult base flow securing and maintenance. For example, CWs which treat high concentration nutrients from agricultural and livestock regions may have a larger CW size to secure sufficient hydraulic retention time (HRT). In urban areas, on the other hand, CWs are established for stormwater runoff treatment mostly on a small scale due to the intermittent inflow and the limited available space. Therefore, a CW may be over-designed in an urban area, if a uniform CW size design rule is applied. Hence, the CW size should be flexibly determined by considering the land use and the influent pollutant removal efficiency. In this study, we propose a novel method of estimating an appropriate CW size by calculating the ratio of the service area to catchment area (SA/CA ratio) of a CW according to the pollutant removal efficiency, as shown in Fig. 1. The CW SA/CA ratio was estimated by considering removal efficiencies of total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP). This resulted to relatively small R^2 value for TN and TP removal efficiencies. This is because the TN and TP removal efficiency is affected by various factors relating to the nutrient removal mechanism such as plants, microorganisms and physicochemical mechanisms [15,18,59–61]. Eq. (1) can be used to determine the surface area of the wetland with data of catchment area and removal efficiency of pollutants as follows:

$$\text{SA/CA (\%)} = \alpha \ln(\text{RE}_i) + \beta \tag{1}$$

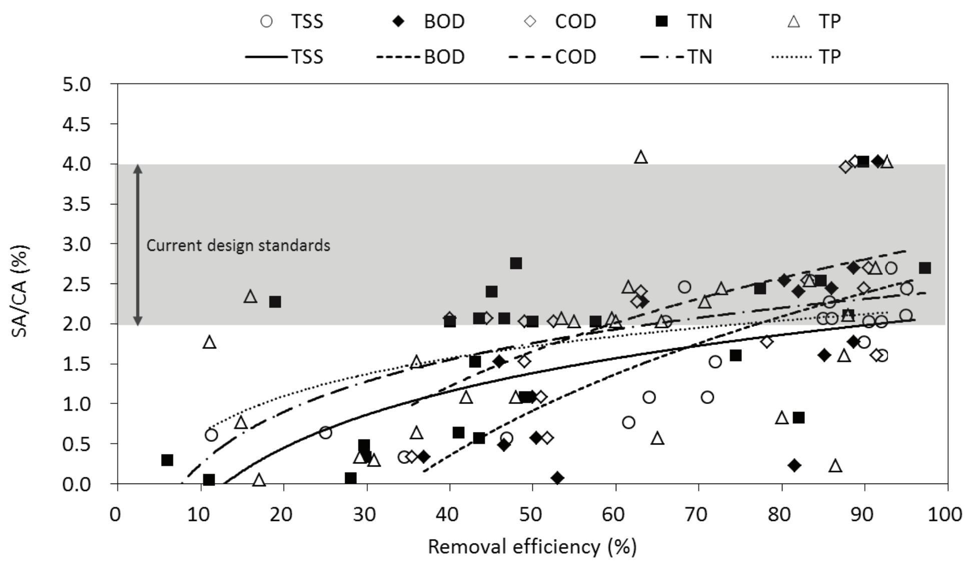
where α, β = constant; i = pollutant parameters such as TSS, BOD, COD, TN and TP; RE_i = removal efficiency of pollutant i (%).

Characteristics of influent should be considered important in a CW size design. As based on the target pollutants, the wetland size can be determined using Eq. (1) and Fig. 2. Table 2 shows the characteristics of influence according to the catchment land uses. A CW size needs to be designed by considering COD and TN in agricultural and livestock regions, while TSS should be considered in an urban region. When COD and TN are supposed to be reduced by an amount of 50% in agricultural and livestock regions, a CW size having an SA/CA ratio of 1.6%–1.7% is appropriate. When TSS is supposed to be removed by about 50%–60% in an urban area, a CW size having an SA/CA ratio of 1.4%–1.6% is appropriate.

Type of CW should be decided by considering the characteristics of the catchment and influent. Appropriate CW size according to CW types should be also determined by considering the water quality goal of the influent. The CW size calculation formula presented above is a formula suggested without considering CW types. In this section, we propose a

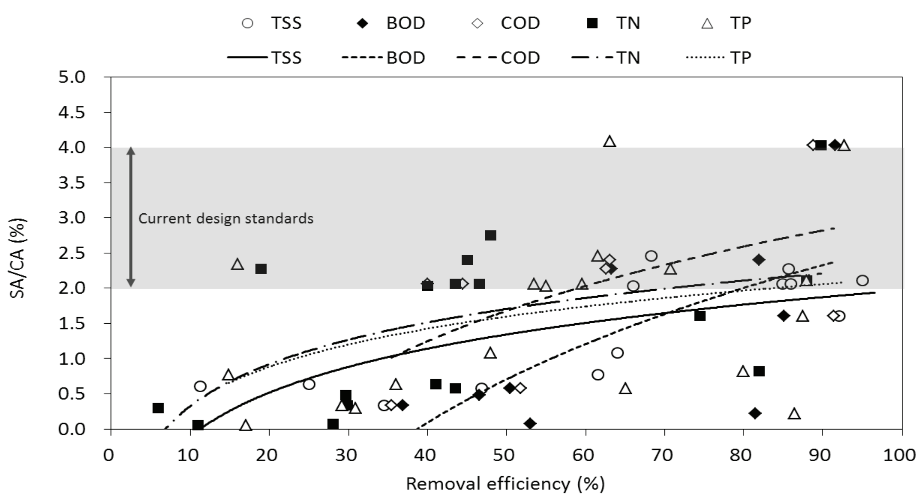
Table 1
Current status of literature-surveyed CWs

References	Location	Type	SA (m^2)	CA (m^2)	SA/CA (%)
[16]	US	FWS	2,400	6,400	37.5
[17,18]	US	FWS	260,000	22,600,000	1.15
[19]	US	FWS	700	29,000	2.41
[20]	US	FWS	2,400	393,000	0.61
[21]	US	FWS	95,100	NA	NA
[22]	Taiwan	FWS	23,000	10,300,000	0.22
[23]	Spain	FWS	64,802	NA	NA
[24]	US	FWS	121,000	40,500,000	0.3
[25]	US	FWS	48	2,000	2.4
[26]	US	FWS	3,600	130,700	2.75
[26]	US	FWS	500	23,700	2.11
[27]	US	FWS	1,300	64,000	2.03
[27]	US	FWS	864	105,000	0.82
[28]	US	FWS	47,176	NA	NA
[28]	US	FWS	18,218	NA	NA
[29]	US	FWS	1,019,807	NA	NA
[30]	S. Korea	FWS	52	3,200	1.61
[31]	Finland	FWS	6,000	120,000	5
[31]	Finland	FWS	4,800	900,000	0.53
[32,33]	S. Korea	FWS	4,492	110,000	4.08
[34]	US	FWS	52,400	2,130,000	2.46
[35]	US	FWS	129,499	11,978,695	1.08
[36]	S. Korea	FWS	4,181	103,800	4.03
[36,37]	S. Korea	FWS	5,010	220,200	2.28
[38]	S. Korea	FWS	12,705	2,210,000	0.57
[38]	S. Korea	FWS	3,282	4,650,000	0.07
[38]	S. Korea	FWS	2,491	750,000	0.33
[39]	S. Korea	FWS	3,491	640,000	0.55
[40]	US	FWS	61,000	2,600,000	2.35
[41]	US	FWS	1,250	162,000	0.77
[42]	US	FWS	450	900,000	0.05
[43]	US	FWS	660	10,000	6.6
[44]	US	FWS	1,416	25,495	5.56
[45]	Greece	FWS	57	2,750	2.06
[45]	Greece	FWS	57	2,750	2.06
[46]	Taiwan	FWS	154,976	NA	NA
[47]	US	FWS	14,200	2,230,000	0.64
[48,49]	US	FWS	25,000	380,000	6.58
[50]	S. Korea	HSSF	7	460	1.52
[51]	S. Korea	HSSF	7	600	1.08
[30]	S. Korea	HSSF	24	950	2.54
[30]	S. Korea	HSSF	97	3,600	2.7
[45]	Greece	HSSF	56	2,750	2.03
[45]	Greece	HSSF	56	2,750	2.03
[52]	Czech	HSSF	5,000	281,400	1.78
[52]	Czech	HSSF	806	20,381	3.95
[53]	China	HSSF	7,400	NA	NA
[54]	Spain	Hybrid	890	NA	NA
[55]	US	Hybrid	214,000	4,330,000	4.94
[51]	S. Korea	Hybrid	32	1,298	2.44
[56]	Estonia	Hybrid	NA	NA	NA
[57]	China	Hybrid	134	NA	NA
[58]	Greece	VF	31	NA	NA



Constant	TSS	BOD	*COD*	*TN*	*TP*
α	1.0181	2.5043	1.9549	0.9381	0.6814
β	-2.5985	-8.8813	-5.9906	-1.9096	-0.9439
R^2	0.53	0.46	0.42	0.37	0.15

Fig. 1. Removal efficiency of each pollutant depending on the CW SA/CA ratio.



Constant	TSS	BOD	*COD*	*TN*	*TP*
α	0.901	2.756	1.9376	0.8563	0.7805
β	-2.1817	-10.075	-5.8999	-1.6448	-1.454
R^2	0.52	0.43	0.35	0.30	0.15

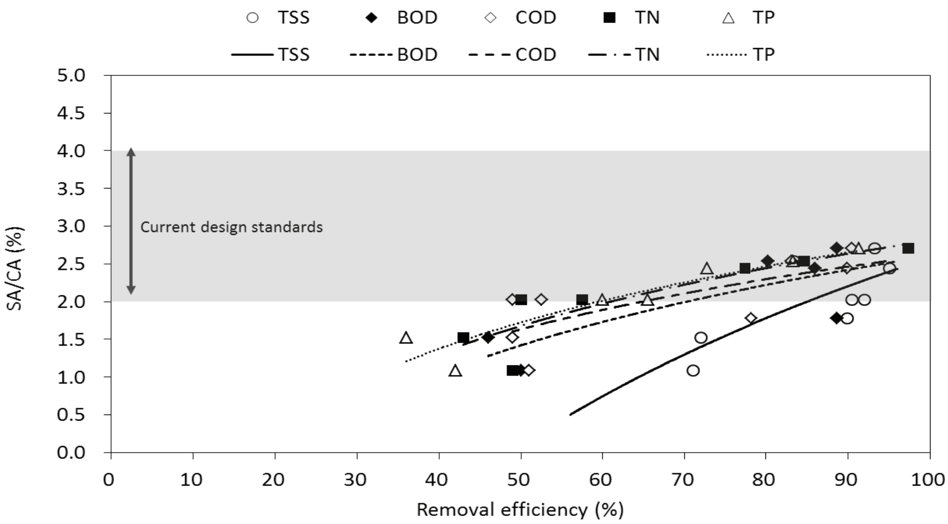
Fig. 2. Pollutant removal efficiency depending on the SA/CA ratio in FWS CW.

formula for calculating appropriate SA/CA ratio for each CW type. As shown in Figs. 2 and 3, the CW size and CW pollutant removal efficiency are proportionally related to each other. Through this approach, the formula to calculate an appropriate CW size with respect to the target influent pollutant removal efficiency is decided during CW design for an FWS CW and other CWs (HSSF, VF and hybrid). For example, when the target TSS removal efficiency is 60%, the SA/CA ratio in FWS is 1.5% and 0.75% in other types of CW. This indicated that other CWs such as HSSF were more effective than an

Table 2
Pollutant concentration according to catchment land uses (mean ± SD)

Parameter	No. of data	Unit	TSS	BOD	COD	TN	TP	References
Agricultural	15	mg/L	20 ± 13	4.3 ± 1.8	17 ± 5.9	4.5 ± 1.9	0.5 ± 0.4	[62]
Livestock	16	mg/L	62 ± 26	69 ± 37	138 ± 61	146 ± 47	5.5 ± 2.1	[63]
Urban[a]	45	mg/L	76 ± 95	17 ± 10	33 ± 17	4.3 ± 2.8	0.8 ± 0.4	[64]
Mix (forest [73%], agricultural [25%], urban [2%])	14	mg/L	40 ± 33	6.7 ± 1.7	15 ± 3	8.2 ± 0.7	1.2 ± 0.3	[65]

[a]Event mean concentration for urban area.



Constant	TSS	BOD	COD	TN	TP
α	3.5918	1.7029	1.4135	1.6291	1.5738
β	-13.959	-5.2413	-3.8969	-4.6963	-4.4309
R^2	0.58	0.64	0.55	0.77	0.87

Fig. 3. Pollutant removal efficiency depending on the SA/CA ratio in HSSF/VF/hybrid CWs.

FWS CW in removing TSS. With respect to nitrogen, when the target removal efficiency is 60%, the SA/CA ratio is 1.85% in an FWS CW and 2.0% in other CW types, indicating that an FWS CW is more effective in nitrogen removal.

3.2. Cost-effective design criteria of forebay size

Generally, the suggested capacity of a CW forebay is more than 10% of water quality treatment volume and the maximum water depth range is 1.0–2.0 m [39]. However, such uniform standards have been suggested without considering the removal efficiency of particulate matter contained in influent, and thus may cause over-design or under-design of a forebay size. Since a forebay is formed to settle and remove settable particulate matter included in the influent, the forebay size should be determined by considering the particulate matter removal efficiency. Fig. 4 shows the relationship between the forebay size and the TSS removal efficiency and the relationship between the forebay HRT and the forebay TSS removal efficiency. The TSS removal efficiency (TSS_F/TSS_T) and the forebay size (SA_F/SA_T) show that the TSS removal efficiency is increased as the forebay surface area is increased. In addition, as the forebay TSS removal efficiency is increased, the forebay HRT is drastically increased. Therefore, in the design of a forebay, the forebay surface area and the HRT should be estimated by considering the target TSS removal efficiency. For example, if the target TSS removal efficiency in a forebay is only 30% of the entire TSS removal efficiency, the surface area of the forebay should be about 12% of the entire CW area and the forebay HRT should be about 4 h. Therefore, appropriate forebay size and HRT may be estimated by using such empirical models shown in Eqs. (2) and (3):

$$\frac{SA_F}{SA_T}(\%) = 8.1602\ \exp^{1.2564\left(\frac{RE\ TSS_F}{RE\ TSS_T}\right)} \tag{2}$$

$$HRT_F(h) = 1.0346\ \exp^{0.0463(RE\ TSS_F)} \tag{3}$$

where SA_F = surface area of the forebay (m^2); SA_T = total surface area of the CW (m^2); RE TSS_F = TSS removal efficiency

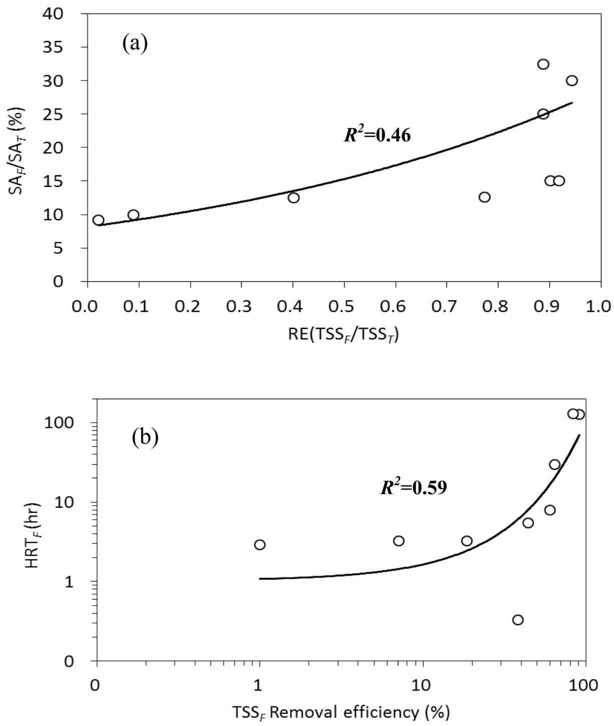


Fig. 4. Relationship of TSS removal efficiency with forebay size and HRT. (a) Relationship between forebay size and TSS removal efficiency and (b) relationship between forebay HRT and forebay TSS removal efficiency.

in the forebay (%); RE TSS_T = TSS removal efficiency in the CW (%); HRT_F = hydraulic retention time in the forebay (h).

Fig. 5 shows the contour models for the calculation of appropriate forebay size according to CW types using the SA/CA ratio, SA_F/SA_T ratio and TSS removal efficiency. The R^2 value was 0.9 or higher, indicating high correlation. When the target TSS removal efficiency in an entire CW is 80% or higher, the SA/CA ratio range is 1.0%–3.2% and the ratio of 2.0%–43.0% in an FWS CW, while there are 1.2%–5.9% and 4.0%–25.0% in an HSSF/hybrid CW, respectively.

3.3. Cost-effective design criteria of vegetation coverage rate

Vegetation coverage is considered to be a key factor controlling nitrogen removal in wetlands [23]. The SA/CA and vegetation coverage showed low correlations. However, the correlation between vegetation coverage and pollutant removal efficiency was separately examined and showed that the correlation was high (R^2> 0.6) as presented in Fig. 6. Therefore, appropriate vegetation coverage for effective nutrient removal efficiency may be calculated by using the correlation with the nutrient removal efficiency (Eqs. (4) and (5)):

$$VC(\%) = 6.2057\ \exp^{0.0264\,(RE_{TN})} \tag{4}$$

$$VC(\%) = 3.3014\ \exp^{0.035\,(RE_{TP})} \tag{5}$$

where VC = Vegetation (or plant) coverage (%); RE_{TN} = TN removal efficiency (%); RE_{TP} = TP removal efficiency (%).

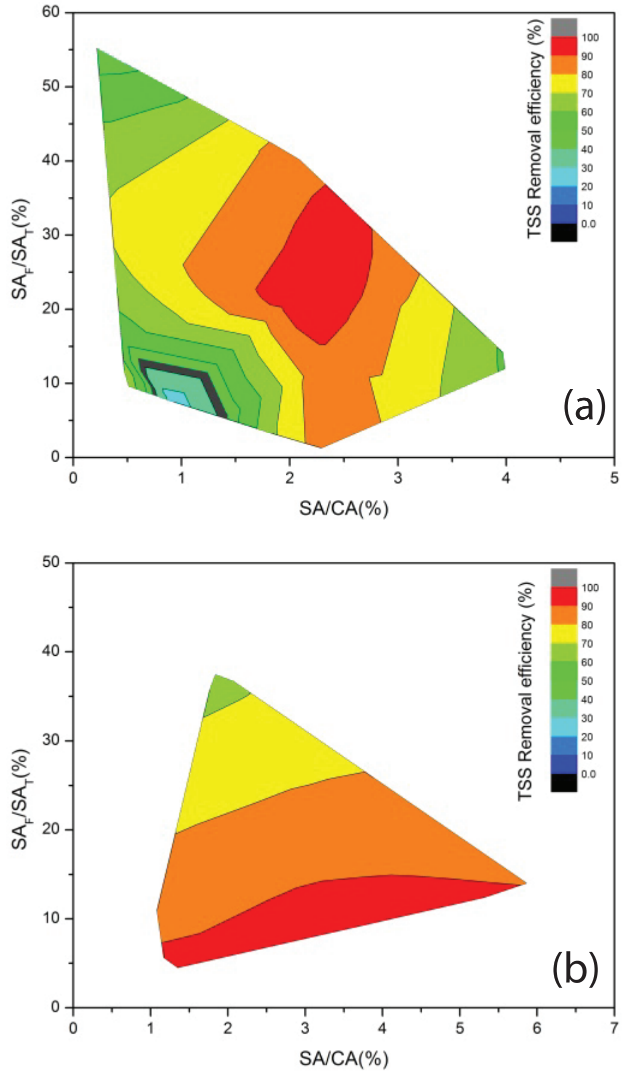


Fig. 5. TSS removal efficiency depending on SA/CA and SA_F/SA_T ratios in each CW type. (a) FWS and (b) HSSF/hybrid.

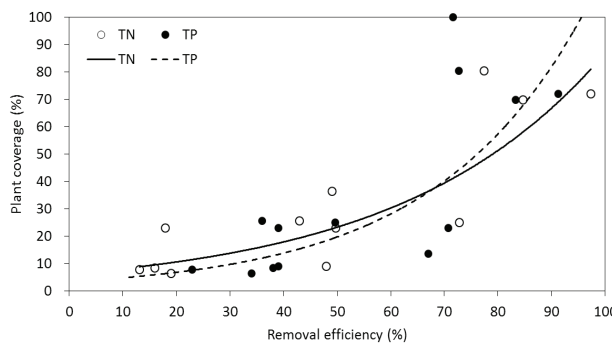


Fig. 6. Calculation of vegetation coverage according to nutrient removal efficiency.

For example, when a CW is designed with a nutrient removal efficiency goal of about 60%–70%, an appropriate range of vegetation coverage is about 30%–40%.

4. Conclusions and recommendations

Recently, CWs for various purposes are designed and maintained to recover damaged water circulation and expand the ecological system in response to the changes in climate and watersheds. However, overemphasizing a specific purpose made the CWs fail in accomplishing their basic purpose of being efficient and ecology wise. This is due to the failure of harmoniously connecting the integrated functions of a CW. Hence, to accomplish the original purposes of a CW decided at the time of CW design, it is necessary to prepare a guideline for the design and maintenance. To prepare a CW design guideline, this study investigated 53 CWs through literature. On the basis of the results, we prepared an appropriate method of CW formation and a guideline for CW design.

Design of a CW requires detailed standards for cost-effectiveness with respect to important design factors. In other words, it is necessary to estimate appropriate CW size, determine a proper forebay size, calculate appropriate vegetation coverage and estimate the installation cost per pollutant reduction according to the target removal efficiency of the pollutants included in the influent by considering the characteristics of the water basin. In this study, the characteristics of possible influent from a water basin to derive a mathematical formula to calculate an appropriate CW size according to the catchment area and another formula to calculate an appropriate CW size according to the CW types were considered. In addition, we developed formulas to calculate an appropriate forebay size and the forebay HRT according to the entire CW area by using the removal efficiency of TSS, which is particulate matter. For an appropriate design of a wetland part where plant growth is active, we also developed a formula to calculate appropriate vegetation coverage by using the target nutrient removal efficiency. Results obtained are intended for use by consulting engineers, landscape architects, environmental regulators, catchment managers, local authorities, academics and any organizations involved in water quality management part.

References

[1] G.D. Ji, T.H. Sun, Q.X. Zhou, X. Sui, S.J. Chang, P.J. Li, Constructed subsurface flow wetland for treating heavy oil-produced water of the Liaohe Oilfield in China, Ecol. Eng., 18 (2002) 459–465.
[2] J. Vymazal, Constructed wetlands for wastewater treatment: five decades of experience, Environ. Sci. Technol., 45 (2011) 61–69.
[3] G. Langergraber, Numerical modelling: a tool for better constructed wetland design?, Water Sci. Technol., 64 (2011) 14–21.
[4] W. Zhi, G. Ji, Constructed wetlands, 1991–2011: a review of research development, current trends, and future directions, Sci. Total Environ., 441 (2012) 19–27.
[5] J. Nivala, T. Headley, S. Wallace, K. Bernhard, H. Brix, M. van Afferden, R.A. Müller, Comparative analysis of constructed wetlands: the design and construction of the ecotechnology research facility in Langenreichenbach, Germany, Ecol. Eng., 61 (2013) 527–543.
[6] A.A. Ansari, S.S. Gill, R. Gill, G.R. Lanza, L. Newman, Phytoremediation, Springer International Publishing, 2016.
[7] D. Konnerup, T. Koottatep, H. Brix, Treatment of domestic wastewater in tropical, subsurface flow constructed wetlands planted with Canna and Heliconia, Ecol. Eng., 35 (2009) 248–257.
[8] D.F. Fink, W.J. Mitsch, Seasonal and storm event nutrient removal by a created wetland in an agricultural watershed, Ecol. Eng., 23 (2004) 313–325.
[9] G.D. Ji, T.H. Sun, J.R. Ni, Surface flow constructed wetland for heavy oil-produced water treatment, Bioresour. Technol., 98 (2007) 436–441.
[10] M. Scholz, A. Hedmark, Constructed Wetlands Treating Runoff Contaminated with Nutrients, Water Air Soil Pollut., 205 (2010) 323–332.
[11] W.J. Mitsch, K.M. Wise, Water quality, fate of metals, and predictive model validation of a constructed wetland treating acid mine drainage, Water Res., 32 (1998) 1888–1900.
[12] F. Zurita, J.D. Anda, M.A. Belmont, Treatment of domestic wastewater and production of commercial flowers in vertical and horizontal subsurface-flow constructed wetlands, Ecol. Eng., 35 (2009) 861–869.
[13] D.P.L. Rousseau, E. Lesage, A. Story, P.A. Vanrolleghem, P.N. De, Constructed wetlands for water reclamation, Desalination, 218 (2008) 181–189.
[14] C.G. Lee, T.D. Fletcher, G. Sun, Nitrogen removal in constructed wetland systems, Eng. Life Sci., 9 (2009) 11–22.
[15] J.N. Carleton, T.J. Grizzard, A.N. Godrej, H.E. Post, Factors affecting the performance of stormwater treatment wetlands, Water Res., 35 (2001) 1552–1562.
[16] C. Athanas, J.C. Stevenson, The Use of Artificial Wetlands in Treating Stormwater Runoff, Final Report submitted to the Sediment and Stormwater Administration, Water Resources Administration, Maryland Department of Natural Resources, USA, 1991.
[17] R.G. Brown, Effects of an urban wetland on sediment and nutrient loads in runoff, Wetlands, 4 (1985) 147–158.
[18] E.W. Strecker, J.M. Kersnar, E.D. Driscoll, R.R. Horner, The Use of Wetlands for Controlling Stormwater Pollution, Prepared for U.S. EPA by Woodward Clyde Consultants, USA, 1992.
[19] J.N. Carleton, T.J. Grizzard, A.N. Godrej, H.E. Post, L. Lampe, P.P. Kenel, Performance of a constructed wetland in treating urban stormwater runoff, Water Environ. Res., 72 (2000) 295–304.
[20] City of Baltimore, Detention Basin Retrofit Project and Monitoring Study Results, Department of Public Works, Bureau of Water and Wastewater, Water Quality Management Office, Baltimore, MD, USA, 1989.
[21] C.W. Downer, T.E. Myers, Monitoring of Sediments and Nonpoint Source Pollution Removal at the Spring Creek Wetland Project, Bowman-Haley Lake, North Dakota, U.S. Army Corps of Engineers, Wetlands Research Program, Technical Report WRP-SM-18, USA, 1995.
[22] C.H. Fan, F.C. Chang, C.H. Ko, Y.S. Sheu, C.J. Teng, T.C. Chang, Urban pollutant removal by a constructed riparian wetland before typhoon damage and after reconstruction, Ecol. Eng., 35 (2009) 424–435.
[23] A. García-Lledó, O. Ruiz-Rued, A. Vilar-Sanz, L. Sala, L. Bañeras, Nitrogen removal efficiencies in a free water surface constructed wetland in relation to vegetation coverage, Ecol. Eng., 37 (2011) 678–684.
[24] A.L. Goldstein, Upland Detention/Retention Demonstration Project Final Report, South Florida Water Management District, Technical Report 86-2, Florida, USA, 1986.
[25] J. Hathaway, W.F. Hunt, A. Johnson, City of Charlotte Pilot BMP Monitoring Program Edwards Branch Wetland Final Monitoring Report, North Carolina State University, Biological and Agricultural Engineering, Raleigh, NC, USA, 2007.
[26] W.F. Hunt, R.J. Winston, S.G. Kennedy, Final Report: Evaluation of Floating Wetland Islands (FWIs) as a Retrofit to Existing Stormwater Detention Basins, NCDENR – Division of Water Quality, NC DENR Contract Number: 1653, USA, 2012.
[27] J.L. Johnson, Evaluation of Stormwater Wetland and Wet Pond Forebay Design and Stormwater Wetland Pollutant Removal Efficiency, Thesis, North Carolina State University, USA, 2006.
[28] R.H. Kadlec, S.B. Roy, R.K. Munson, S. Charlton, W. Brownlie, Water quality performance of treatment wetlands in the Imperial Valley, California, Ecol. Eng., 36 (2010) 1093–1107.

[29] R.H. Kadlec, J.S. Bays, L.E. Mokry, D. Andrews, M.R. Ernst, Performance analysis of the Richland-Chambers treatment wetlands, Ecol. Eng., 37 (2011) 176–190.
[30] Korea Institute of Construction Technology (KICT), Best Management Practices Monitoring for Treating Stormwater Runoff from Road: Final report, Korea Institute of Construction Technology, South Korea, 2013.
[31] J. Koskiaho, Flow velocity retardation and sediment retention in two constructed wetland–ponds, Ecol. Eng., 19 (2003) 325–337.
[32] S.Y. Lee, M.C. Maniquiz, J.Y. Choi, S.M. Jeong, L.H. Kim, Seasonal nutrient uptake of plant biomass in a constructed wetland treating piggery wastewater effluent, Water Sci. Technol., 67 (2013) 1317–1323.
[33] Ministry of Environment (MOE), The BMPs Management and Maintenance Study, Final report, Ministry of Environment, South Korea, 2013.
[34] K. McCann, L. Olson, Final Report on Greenwood Urban Wetland Treatment Effectiveness, Florida Department of Environmental Protection, Project WM427, USA, 1994.
[35] E.C. Meiorin, Urban Runoff Treatment in a Fresh/Brackish Water Marsh in Fremont, California, Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural, D.A. Hammer, Eds., Lewis Publishers, Inc, Chelsea, 1989, pp. 677–685.
[36] Ministry of Environment (MOE), The BMPs Management and Maintenance Study in Han River Watershed, Final Report, Ministry of Environment, South Korea, 2008.
[37] Q. Yi, Nonpoint Source Pollution Control Using Constructed Wetland in the Agricultural Area, PhD Dissertation, Hanseo University, Seosan City, South Korea, 2010.
[38] Ministry of Environment (MOE), The BMPs Management and Maintenance Study in Geum River Watershed, Final Report, Ministry of Environment, South Korea, 2009.
[39] Ministry of Environment (MOE), Manual for the BMPs Installation, Management and Maintenance, Ministry of Environment, South Korea, 2014.
[40] S.F. Niswander, W.J. Mitsch, Functional analysis of a two-year-old created in-stream wetland: hydrology, phosphorus retention, and vegetation survival and growth, Wetlands, 15 (1995) 212–225.
[41] Occoquan Watershed Monitoring Laboratory (OWML) and Department of Biology, George Mason University, Final Project Report, The Evaluation of a Created Wetland as an Urban Best Management Practice, Virginia, USA, 1990.
[42] G.W. Raisin, D.S. Mitchell, R.L. Croome, The effectiveness of a small constructed wetland in ameliorating diffuse nutrient loadings from an Australian rural catchment, Ecol. Eng., 9 (1997) 19–35.
[43] J.E. Reuter, T. Djohan, C.R. Goldman, The use of wetlands for nutrient removal from surface runoff in a cold climate region of California results from newly constructed wetland at lake Tahoe, J. Environ. Manage., 36 (1992) 35–53.
[44] B.T. Rushton, C.W. Dye, An In Depth Analysis of a Wet Detention Storm Water System, Southwest Florida Water Management District, Brooksville, FL, USA, 1993.
[45] S. Terzakis, M.S. Fountoulakis, I. Georgaki, D. Albantakis, I. Sabathianakis, A.D. Karathanasis, N. Kalogerakis, T. Manios, Constructed wetlands treating highway runoff in the central Mediterranean region, Chemosphere, 72 (2008) 141–149.
[46] Y.T. Tu, P.C. Chiang, J. Yang, S.H. Chen, C.M. Kao, Application of a constructed wetland system for polluted stream remediation, J. Hydrol., 510 (2014) 70–78.
[47] B. Urbonas, J. Carlson, B. Vang, Joint Pond-Wetland System Performance in Colorado, USA, Internal Report of the Urban Drainage and Flood Control District, Denver, CO, USA, 1994.
[48] P. Wotzka, G. Oberts, The water quality performance of a detention basin-wetland treatment system in an urban area, Proceedings of the symposium on Nonpoint pollution: policy, economy, management, and appropriate technology, J. Am. Water Resour. Assoc., (1988) 237–247.
[49] G.L. Oberts, R.A. Osgood, Water-quality effectiveness of a detention/wetland treatment system and its effect on an urban lake, Environ. Manage., 15 (1991) 131–138.
[50] J.Y. Choi, M.C. Maniquiz-Redillas, S.Y. Lee, J.M.R. Mercado, L.H. Kim, Application of a gravel wetland system for treatment of parking lot runoff, Desal. Wat. Treat., 51 (2013) 4129–4137.
[51] Ministry of Land, Infrastructure and Transport (MOLIT), Development of Hybrid Constructed Wetland and Permeable Artificial Riprap Water Front Structures for Coastal Zone Green Growth, Final Report, Ministry of Land, Infrastructure and Transport, South Korea, 2013.
[52] J. Vymazal, The use constructed wetlands with horizontal sub-surface flow for various types of wastewater, Ecol. Eng., 35 (2009) 1–17.
[53] W. Wang, J. Gao, X. Guo, W. Li, X. Tian, R. Zhang, Long-term effects and performance of two-stage baffled surface flow constructed wetland treating polluted river, Ecol. Eng., 49 (2012) 93–103.
[54] P. Arroyo, G. Ansola, E. de Luis, Effectiveness of a full-scale constructed wetland for the removal of metals from domestic wastewater, Water Air Soil Pollut., 210 (2010) 473–481.
[55] J.M. Barten, Stormwater runoff treatment in a wetland filter: effects on the water quality of Clear Lake, Lake Reservoir Manage., 3 (1987) 297–305.
[56] M. Öövel, A. Tooming, T. Mauring, Ü. Mander, Schoolhouse wastewater purification in a LWA-filled hybrid constructed wetland in Estonia, Ecol. Eng., 29 (2007) 17–26.
[57] F. Ye, Y. Li, Enhancement of nitrogen removal in towery hybrid constructed wetland to treat domestic wastewater for small rural communities, Ecol. Eng., 35 (2009) 1043–1050.
[58] G.D. Gikas, V.A. Tsihrintzis, A small-size vertical flow constructed wetland for on-site treatment of household wastewater, Ecol. Eng., 44 (2012) 337–343.
[59] T.R. Schueler, Design of Stormwater Wetland Systems: Guidelines for Creating Effective and Diverse Stormwater Wetlands in the Mid-Atlantic Region, Metropolitan Washington Council of Governments, 1992.
[60] T. Zhu, Phosphorus and Nitrogen Removal in Lightweight Aggregate (LWA) Constructed Wetlands and Intermittent Filter Systems, PhD Thesis, Agricultural University of Norway, Norway, 1998.
[61] A. Drizo, C.A. Frost, J. Grace, K.A. Smith, Phosphate and ammonium distribution in a pilot-scale constructed wetland with horizontal subsurface flow using shale as a substrate, Water Res., 34 (2000) 2483–2490.
[62] J.Y. Choi, M.C. Maniquiz, B.S. Lee, S.M. Jeong, L.H. Kim, Characteristics of contaminant and phosphorus existence types in sediment of a constructed wetland, Desal. Wat. Treat., 38 (2012) 285–291.
[63] S.Y. Lee, M.C. Maniquiz, L.H. Kim, Characteristics of contaminants in water and sediment of a constructed wetland treating piggery wastewater effluent, J. Environ. Sci., 22 (2010) 940–945.
[64] M.C. Maniquiz, S.Y. Lee, L.H. Kim, Multiple linear regression models of urban runoff pollutant load and event mean concentration considering rainfall variables, J. Environ. Sci., 22 (2010) 946–952.
[65] M.C. Maniquiz, S.Y. Lee, J.Y. Choi, S.M. Jeong, L.H. Kim, Treatment performance of a constructed wetland during storm and non-storm events in Korea, Water Sci. Technol., 65 (2012) 119–126.