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Sewage Treatment Using Natural Systems and Effluent Reuse for Crop Irrigation in Small Communities

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Abstract

A pilot study was performed from July 1998 to December 2002, including winter performance, to examine seasonal performance of a constructed wetland and subsequent pond system for treatment of sewage in small communities of Korea. Pond was operated as a intermittent-discharge pond during winter period, and continuous flow system during growing season; its effects was evaluated from December 2001 to April 2003.

The subsurface flow (SSF) wetland was satisfactory for treating sewage with good removal efficiency even during the winter period. The wetland effluent concentrations of BOD_5 and TSS were often higher in winter than in the growing season, but this was explained by the higher loading rates, rather than lower removal efficiency. The relatively poor-quality wetland effluent was further polished during winter in the pond. The upper layer of the pond water column became remarkably clear immediately after ice melt. In the growing season, ponds could be operated as a continuous flow system to remove nutrients and pathogens, and the effluent of pond could be reused as a supplemental irrigation water without risk of infection by sewage-borne pathogens as well as causing adverse effect on growth and yield.

Overall, the wetland system was found to be adequate for treating sewage with stable removal efficiency, and the intermittent-discharge pond was found to be effective for further polishing if necessary. Therefore, the combination of a wetland and subsequent pond system and reuse of effluent as crop irrigation water is recommended as a practical alternative to treat sewage in Korean small communities, and partial discharge of pond water in March is suggested.

Keywords : Constructed wetland; Sewage treatment; Intermittent-discharge pond; Partial discharge; Reuse

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I. Introduction

Treatment wetlands are engineered systems designed to use the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating wastewater. Pollutants are removed through a combination of physical, chemical, and biological

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processes including sedimentation, precipitation, adsorption to soil particles, assimilation by the plant tissue, and microbial transformations (Reed et al., 1995). Like any other biological wastewater treatment process, constructed wetland treatment relies largely on biological and biochemical processes. Biological and biochemical reactions are temperature dependent and thus, the performance during winter months might be reduced.

If a constructed wetland is insulated from the weather, substantial reductions of BOD_5, TSS, and nutrients still might be possible at low ambient temperatures. Thus, it would be possible to successfully use constructed wetlands for wastewater treatment in cold climates (Wittgren and Mæhlum, 1997). Constructed wetlands can be insulated both by natural material (e.g. straw, ice, snow) and artificial material (e.g., rockwool, polystyrene foam). If the plant material in the wetland is not harvested, it also will provide insulation, as will snow and ice within the system. Wallace et al. (2001) used mulch as an insulation material and found it to be highly effective in keeping the system from freezing. In the warm temperate region (mean temperature of coldest months: −3 ~ 18 ℃), winter problems are only occasional and the design of the wetlands to compensate for poor performance during winter raises capital and operating costs. Constructed wetland systems in warm temperate regions require special operational strategies during winter to avoid discharges of relatively poor-quality effluents to receiving waters. Winter conditions also leave the receiving waters at their lowest flow rate of the year, which limits the dilution ratio available for the wastewater.

Wittgren and Mæhlum (1997) reported that in a national survey of 67 wetlands treating wastewater or stormwater in Canada, wastewater was stored in ponds during the winter and then discharged to the wetland during the spring, summer, and fall at several locations. The advantage of this approach is to use warm weather design for the wetland, but it requires additional storage ponds. Heaven et al. (2002) reported that the use of reservoirs to store treated, partially treated, and untreated wastewater from cities and industrial enterprises is common in Kazakhstan and central Asia. An estimated 540 collector reservoirs of this type are operating in Kazakhstan. The unique features of intermittent discharge ponds are long-term retention and periodic, intermittent discharge usually once or twice a year (US EPA, 1983). The database of lagoon effluent quality showed that season of discharge, month of discharge, storage time, and lagoon configurations were important factors in determining effluent quality (Price et al., 1995).

The effluent of wetland and pond effluent could be reused as supplemental irrigation water for agriculture. The suspended, colloidal, and dissolved solids present in sewage contain major plant nutrients (nitrogen, phosphorus and potassium) and also trace nutrients (such as copper, iron and zinc), but may not contain toxic compound such as heavy metals (Mara and Cairncross, 1989). Kwun et al. (2001) examined the agronomic application of the treated sewage using constructed wetland on paddy rice culture through field experiment. They reported that irrigation with the treated sewage showed a better result, with the yield exceeding that of the control where clean water was used, thus suggesting that reuse of the treated sewage as supplemental irrigation water could be a feasible and practical alternative. In the past two decades there has been a great increase in the use of wastewater for crop irrigation, especially in semiarid areas of both developed and developing countries (Mara and Cairncross, 1989). But municipal wastewater contains correspondingly high concentrations of excreted pathogens causing excreta-related diseases. To reuse treated sewage as crop irrigation water, pathogens levels of the irrigation water must be considered.

A pilot study was performed to investigate seasonal performance of a constructed wetland and subsequent pond system for sewage treatment in Korea, where the latter was connected to provide further polishing of relatively poor-quality wetland effluent.

Ⅱ. Materials and Methods

1. Experimental System

An experimental constructed wetland was installed and has been working continuously since 1997 on the campus of Konkuk University in Seoul, Korea. The treatment basin (8 m long, 2 m wide, 1 m deep) was filled with sand and planted with common reed (*Phragmites australis* Cav.). Walls and bottom of the basin were built with concrete, and the bottom slope was 1% towards the outlet (Fig. 1). The void ratio and specific gravity of the sand used to fill the basin were 0.36 and 2.64, respectively. Hydraulic loading rate and hydraulic residence time of the system were 6.3 cm/day and 3.5 days, respectively.

The wetland system was maintained by a continuous flow with no artificial thermal insulation. The average ambient air temperature in the winter period (December to February) was −0.2 ℃ for the last 30 years and it occasionally

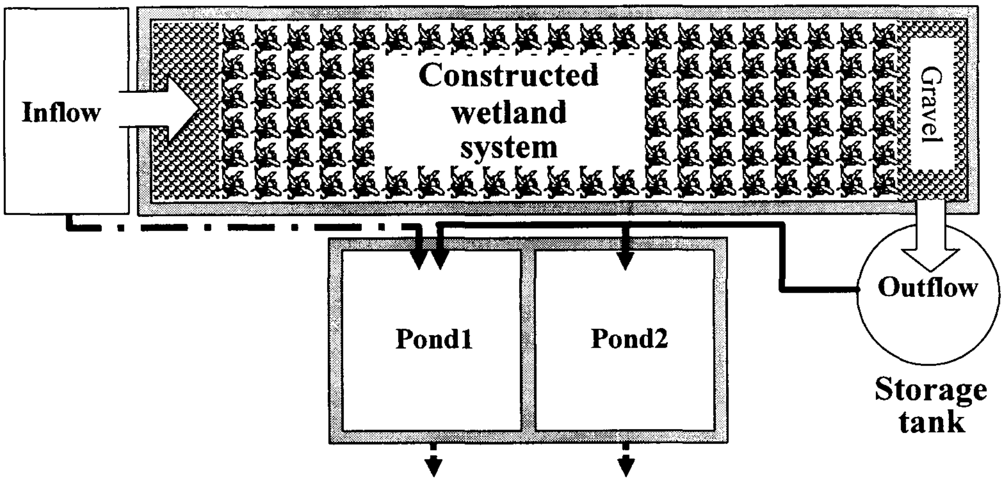

Fig. 1 Schematic layout of the experimental system

dropped below −10 ℃. The sewage used in the experiment originated from a school building, with toilets being the main source of pollutant discharge. A septic tank had been designed to collect the sewage and discharge it to the public sewer system after pre-treatment. The tank had three compartments, and the wastewater in the last compartment was pumped into the storage tank and then allowed to flow into the wetland system. Average water quality of the sewage was pH 7.91, temperature 18.80 ℃, DO 0.40 mg/L, BOD_5 121.96 mg/L, TSS 68.95 mg/L, T-P 13.36 mg/L, and T-N 121.23 mg/L.

To investigate the feasibility of a pond system for further polishing of wetland effluent, two experimental ponds were made with concrete along with the wetland system (Fig. 1). They measured 2.0 m long, 2.0 m wide and 2.0 m deep. The bottom elevation was 1.5 m below the ground surface to minimize temperature effects on the pond water column, and the bottom 0.5 m was filled with sand. The influent was introduced up to the 1.9 m elevation from bottom of the pond (water column 1.4 m and sand 0.5 m).

During phase-1 (December 2001 – June 2002) and phase-3 (December 2002 – April 2003) ponds were operated with intermittent discharge (Table 1). During phase-1, pond-1 was filled with sewage + wetland effluent (SW), and pond-2 was filled with wetland effluent (WT) to monitor the change of water quality under different concentrations. During phase-3, pond-1 and pond-2 were both filled with only wetland effluent. During phase-2 (July 2002 – November 2002) ponds were operated with continuous plug flow. Wetland effluent was introduced into each pond, and hydraulic loading rate and hydraulic retention time were 12.5 cm/day and 11 days, respectively.

2. Analytical Methods

Samples of influent and effluent water from the wetland system were taken with a time lag equal to one hydraulic residence in order to evaluate the wetland system's performance. For the intermittent discharge system, samples were taken from two different depths (0.1 and 0.8 m) using a Van Dorn sampler in phase-1 and from only one depth (0.1 m) in phase-3. For the continuous plug flow system, samples of influent and effluent water were taken with a time lag. Samples were collected in duplicate and water quality parameters, including Chl-*a*, DO, BOD_5, TSS, T-P, T-N and fecal coliform were analyzed by Standard Methods (APHA, 1998).

Table 1 Operational phases during the research period

Phase	Duration	system type	Influent	
			Pond-1	Pond-2
1	Dec. 2001 Jun. 2002	Intermittent- discharge pond	SW[a]	WT[b]
2	Jul. 2002 Nov. 2002	Continuous-flow pond	WT	WT
3	Dec. 2002 Apr. 2003	Intermittent- discharge pond	WT	WT

[a] SW: Sewage + Wetland effluent
[b] WT: Wetland effluent

Four years of experimental data (July 1998 – December 2002) from the wetland system were used for analysis. The data were divided into two groups: winter (December ~ February) and growing season (March ~ November) to analyze seasonal performance. Experimental data from the pond system were collected from December 2001 to April 2003, and were grouped into winter (December ~ February) and spring (March ~ June) seasons. Paired–comparison t–tests were used to examine differences between data groups, and statistical analyses were performed using SPSS for Windows version 10.0.

Ⅲ. Results and Discussion

1. Wetland Performance

The wetland system displayed good performance, in regard to improving wastewater quality (Table 2). While the mean air temperature was below 0 ℃ (−0.5 ± 0.24 ℃) in winter of the study period, the water temperature of wetland effluent was seldom below 5 ℃ and the mean water temperature was 8.1 ℃. Natural wastewater treatment systems could be affected by temperature, because biological and biochemical reactions are temperature dependent. The presumption of a similar kind of temperature dependence has been made for wetlands (Reed, 1995; Newman, 2000). The influent DO was

Table 2 Seasonal comparison of concentrations of the constructed wetland

Constituents		Concentration (mean ± S.D.[a])		p-value
		Growing season	Winter	
Temp. (℃)	Inf.	20.6 ± 6.23	9.9 ± 2.56	0.000^b
	Eff.	19.6 ± 6.25	8.1 ± 1.76	0.000^b
DO (mg/L)	Inf.	0.3 ± 0.61	1.2 ± 1.04	0.001^b
	Eff.	2.4 ± 0.97	2.3 ± 0.83	0.622
BOD_5 (mg/L)	Inf.	116.2 ± 59.61	150.9 ± 75.37	0.025^b
	Eff.	20.9 ± 17.98	62.2 ± 48.63	0.001^b
	Removal (%)	81.0 ± 12.78	61.8 ± 15.13	0.000^b
TSS (mg/L)	Inf.	62.2 ± 36.05	102.7 ± 44.61	0.000^b
	Eff.	14.0 ± 11.40	32.8 ± 19.14	0.000^b
	Removal (%)	71.6 ± 23.34	64.8 ± 20.19	0.226
T-P (mg/L)	Inf.	13.4 ± 4.03	13.0 ± 4.91	0.683
	Eff.	7.1 ± 3.58	8.5 ± 2.81	0.100
	Removal (%)	44.0 ± 33.20	26.8 ± 27.15	0.032^b
T-N (mg/L)	Inf.	121.4 ± 39.28	120.2 ± 46.84	0.904
	Eff.	93.9 ± 35.47	108.0 ± 36.18	0.109
	Removal (%)	20.0 ± 28.00	7.7 ± 12.91	0.003^b

[a] Standard deviation

[b] Significantly different at p=0.05

generally very low because it was pumped from the septic tank, and it was slightly higher in winter ($p < 0.05$) probably due to low temperature. The effluent DO was greater than the influent and generally was above 2.0 mg/L even without any auxiliary aeration. There was no significant difference in DO between winter and growing seasons. This implies that natural oxygen supply could be enough to keep the treatment wetland system aerobic throughout the year.

Removal of BOD_5 was apparent in the wetland system over the entire study period, although the mean effluent concentration was significantly higher ($p < 0.05$) in winter than in the growing season. The mean BOD_5 removal efficiency in winter was lower than in the growing season. A number of other published sources (Gumbricht, 1992) claim that BOD_5 removal in wetlands is not affected by temperature. However, many systems cited by those authors were either lightly loaded and/or had long detention times. The impact of either condition is to mask temperature effect since the wastewater would be treated to near the "background" level for that particular wetland, long before the effluent end is reached. In such systems, the effluent will be roughly the same in winter and summer and is not expected to demonstrate any temperature effects on removal. On the other hand, wetlands with a relatively short detention time, and/or those receiving higher strength wastewater, do demonstrate a significant temperature effect on BOD_5 removal comparing winter to summer results (Wittgren and Mæhlum, 1997). The system of this study falls into the latter case, and a significant temperature effect was observed in the winter season.

The effluent TSS concentration in winter was significantly higher than in the growing season ($p < 0.05$), but no seasonal difference was observed in TSS removal efficiency, which is similar to the finding of other studies (Kadlec and Knight, 1996). The high effluent concentrations might be attributed to relatively higher loading rather than lower removal efficiency due to temperature dependence. The effects of temperature on the properties of water are not sufficient to significantly affect the removal efficiency of TSS in SSF wetlands, because TSS is mainly removed by physical processes (Kadlec and Knight, 1996). TSS settles into stagnant micro-pockets or is constrained by flow restrictions, and may also impinge upon substrate granules and stick as a result of several possible inter-particle adhesion forces (Kadlec and Knight, 1996).

The performance of T-P removal was relatively poor compared to BOD_5 and TSS but better than T-N. Phosphorus removal, being largely a physical (sedimentation) and chemical (adsorption) process, is less directly sensitive to temperature, but may be influenced by the oxygen availability due to the large role played by redox sensitive adsorption to ferrous/ferric oxides (Wittgren and Mæhlum, 1997). In winter, when the plants do not provide oxygen and ice-cap formation restricts aeration of soil and water, the system might turn anaerobic. At the same time, the water solubility of oxygen increases with decreasing temperature and phosphorus release is often associated with oxygen deficiency. Kadlec and Knight (1996) reported that there were no large differences in phosphorus removal associated with temperature or season when viewed from the overall correlative perspective. In this study, effluent concentrations were in the same range for both winter and growing seasons, but the removal efficiency of T−P in winter was lower than in the growing season ($p < 0.05$).

The removal of T−N was poor, and the removal efficiency of T−N in winter was even lower than in the growing season. The processes of ammonification, nitrification, and denitrification have all been shown to be temperature dependent in treatment wetlands; therefore, rates of total nitrogen reduction will also be temperature dependent (Kadlec and Knight, 1996). Nitrification rates appear to be inhibited at water temperatures around 10 ℃, and rates drop rapidly to zero below approximately 6 ℃. Denifrification has been observed to occur at temperatures as low as 5 ℃ (Brodrichk et al., 1988). The low T−N removal efficiency in this study might be due to high influent concentration (over 100 mg/L) and limited hydraulic residence time (3.5 days) of the experimental wetland system.

2. Intermittent-discharge Pond Performance - Winter Period

Figs. 2 and 3 illustrate water quality variation in upper and lower layers of the pond system. The pond system was operated with intermittent discharge during winter (phase−1 and phase−3). During phase−1, initial water quality of T−P and T−N was in the similar range although different types (SW and WT) of influent were used because nutrient removal efficiency of the wetland was low when wetland effluent was used to fill the ponds. About 10 cm ice cap was formed in January 2002 at top of ponds, and by accident the wall of SW pond had a partial crack and water column depth decreased from 1.4 m to 0.8 m. The unintentional air void was made between ice cap and water column until the ice cap was melted. The crack of SW pond was fixed in May 2002 and water level was kept consistently thereafter.

During phase−1, BOD_5 and TSS were reduced substantially, while other constituents, including nutrients, varied little until February. Samples taken from beneath the ice cap indicated a reduction of BOD_5 and TSS, vs. a slight increase in T−P and T−N. Sedimentation and limited biodegradation might result in BOD_5 and TSS reduction, and phosphate and ammonia release from bottom sediments might contribute to the T−P and T−N increase. There was no difference for water quality constituents ($p > 0.05$) between the upper and lower layers during winter (December to February) in phase−1. This implies that the water quality profile was nearly uniform throughout the water column in winter. However, this situation changed in spring, when the WT ponds had higher concentrations of pollutants in the lower layer, while SW continued to have no significant variation with depth. Because water depth of SW was lower than WT, the entire water column of SW was aerobic, so that BOD_5 and nutrients in lower layers could be decayed in a similar manner as in upper layers of the SW.

The T−P and T−N concentrations of upper layers of the water column dropped dramatically in March 2002 and reached the lowest values of the experimental period. This also was observed for BOD_5 and TSS. In cold climates, the effects

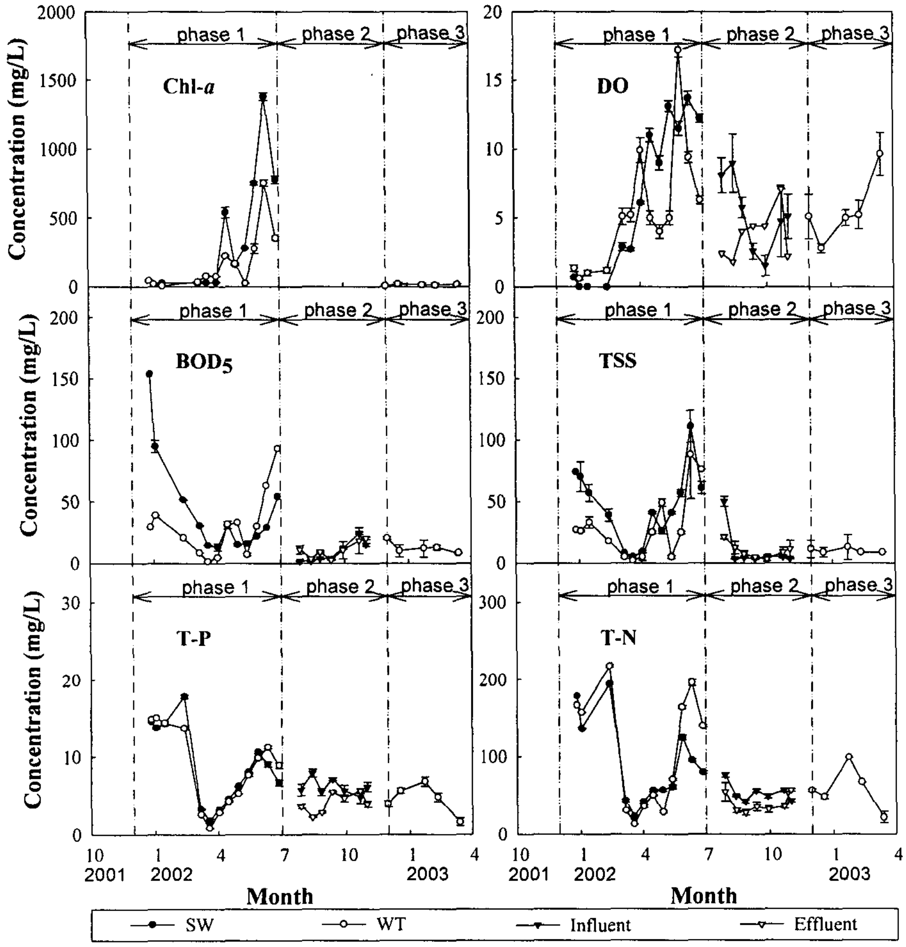

Fig. 2 Water quality variation in the upper pond water column

of freezing and thawing, which convert the jelly-like consistency of sludge to a granular-type material that drains readily, have been observed to improve the dewatering or settling characteristics of sludge. The freezing-thawing effect and resulting settling might partly explain the phenomena in this study. Water quality parameters in both types of ponds demonstrated remarkable improvement after three months of storage in the intermittent-discharge pond during the winter period. Generally they displayed over 90 % removal efficiency in phase-1, and the nutrient reduction in the upper layer was particularly encouraging. During phase-3, a similar pattern was observed where initial concentrations were lower than in phase-1.

Once algae started to grow in mid-April, constituents in the pond water column changed widely and the concentration was closely associated with the biomass of phytoplankton. Phytoplankton biomass tends to be highest in the warm months of late spring through early fall

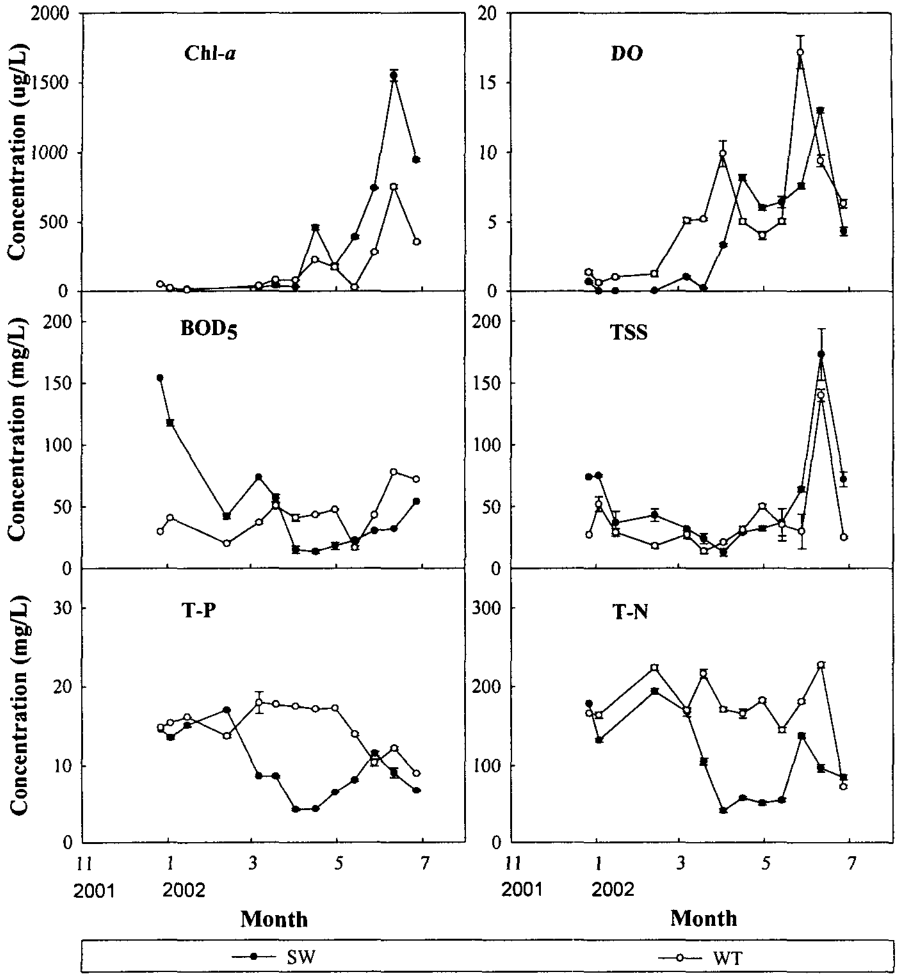

Fig. 3 Water quality variation in the lower pond water column during phase-1

because warm water temperature, seasonally high solar radiation, and large input of plant nutrients (derived from accumulated bottom sediment) support rapid rates of gross primary production (Tucker et al., 1996). It was also reported that pond water quality variables (such as COD, BOD, DO, TSS, T-P, and T-N) are closely associated with the biomass of phytoplankton and phytoplankton-derived detritus (Tucker et al., 1996). The constituent levels were high in the late spring of phase-1, corresponding with an algal bloom levels then decreased during June.

3. Continuous-flow Pond Performance-Growing Season

From July to November 2002, the pond was operated as a continuous flow system. There was no significant difference ($p > 0.05$) in BOD_5 or TSS between influent and effluent, because BOD_5 and TSS concentrations of pond influent were low. Average BOD_5 and TSS concentrations of pond effluent were 10.8 mg/L and 9.9 mg/L, respectively, and were within an acceptable range. Average removal rates of T-P and T-N by the pond were approximately 28 and 25 %, respectively (Table 3). In the same period, T-P and T-N removal rates of the wetland were 23 and 31 %, and total removal rates of the full treatment system (wetland + pond) were about 51 and 56 %, respectively.

Fecal coliform concentrations in wetland or pond effluents are commonly reduced by at least one log unit, but levels below 500 MPN/100mL are difficult to achieve consistently. Although average fecal coliform removal rate was over 90 % in this wetland, average fecal coliform (FC) concentrations of wetland effluent were about 7,900 MPN/100mL, which is still high (Table 3). However, after passage through the pond, fecal coliform (FC) concentrations were reduced by an order of magnitude (about 96 %), averaging just 430 MPN/100mL.

4. Operation and Maintenance

In an intermittent-discharge pond, such as those used here, many factors can affect effluent water quality, including the season of discharge, storage time, and pond configuration. In the USA and Canada control of the discharge operation is seen as the most critical factor in performance of intermittent-discharge pond systems (US EPA, 1983). Both spring and fall discharges are common. Spring discharge may have the advantage of coinciding with peak flows in the receiving watercourse, and of allowing a reduction in storage volume if two annual discharges are possible (Heaven et al., 2002). It was reported that, in general, fall effluent quality is superior to that in spring because of the longer ice-free treatment period preceding discharge (Price et al., 1995). In fall, the typical rapid drop in temperature also kills and removes most of the algae.

In this study, partial discharge of the upper layer of pond water in spring is suggested right after ice melt, when water quality of the upper layer might be significantly better than the lower

Table 3 Pond performance during continuous-flow operation in phase-2

Constituents	Pond influent	Pond effluent	Removal rate	p-value
		(mean ± S.D.[a])		
DO (mg/L)	3.8 ± 0.47	5.3 ± 0.78	-	0.193
BOD_5 (mg/L)	8.9 ± 2.19	10.8 ± 2.11	-	0.305
TSS (mg/L)	10.8 ± 4.44	9.9 ± 1.80	-	0.791
T-P (mg/L)	5.7 ± 0.19	4.1 ± 0.34	28.0 ± 6.57	0.001[b]
T-N (mg/L)	53.0 ± 2.97	38.9 ± 3.27	25.1 ± 6.80	0.001[b]
Fecal coliform (MPN/100 mL)	7883.3 ± 949.90	431.7 ± 65.55	96.1 ± 1.44	0.002[b]

[a] Standard deviation

[b] Significantly different at $p=0.05$

layer. The remaining lower layer could be further treated by re-circulation to the wetland in the growing season. During the winter season, ponds are operated with intermittent-discharge in most wetland-pond systems. After discharge of the pond in spring, ponds are typically operated with a continuous flow to remove nutrients and pathogens (coliform).

5. Agricultural Reuse

In the growing season, pond effluent can be used for crop irrigation (e.g., paddy rice fields in Korea), and in this case, the pond is a storage reservoir for irrigation. Nutrients in the effluent wetland and pond which are important to agriculture include nitrogen, potassium, zinc, boron, and sulfur. In many regions, there is a shortage of fresh water resources that can be used for irrigation. The use of treated sewage for irrigation water provides a vital resource to enhance agricultural productivity. In addition to providing a low cost water source, other side benefits include increases in crop yields, decreased reliance on chemical fertilizers, improving the environment by enabling zero-discharge to receiving bodies, and enabling the reallocation of freshwater supplies for urban use. In Korea, wetland-pond systems can be used in rural areas, especially if paddy fields are located near rural housing. Usually late spring to early summer is a drought period in Korea, when considerable water is required for irrigation.

To reuse pond effluent as crop irrigation water, pathogen levels of the irrigation water must be considered. Pathogenic organisms (viruses, bacteria, protozoa and helminth eggs) may be associated with the transmission of disease to farm workers and other people and to livestock exposed to the effluent either by incidental physical contact, by inhalation of aerosols from spray-irrigated fields or by consuming crops irrigated with effluent (Feigin et al., 1991). Coliform bacteria have long been used for indicator organism and, while others exist, coliforms are still the indicator organism most commonly used despite the fact that not all of them are exclusively fecal (Mara and Cairncross, 1989; Cooper and Olivieri, 1998). Microbiological standards for wastewater used for crop irrigation

Table 4 Microbiological standards for wastewater used for crop irrigation

Category	US EPA	US States	WHO	Recommendation for revising WHO guidelines
unrestricted irrigation	Non detect	2.2-200 : spray irrigation 10-1,000 : surface irrigation	≤1,000	$\leq 10^3$
restricted irrigation	≤200	-	No standard recommended	$\leq 10^5$: Spray/sprinkler irrigation and exposure to adult workers only $\leq 10^3$: flood/furrow irrigation or exposure to children

are shown in Table 4. As given in Table 3, fecal coliform of wetland effluent (pond influent) was still high to reuse as a irrigation water. This was further reduced to less than 500 MPN/100mL in average, showing over 95 % removal after pond treatment. And fecal coliform levels in this pond effluent met WHO guidelines and satisfied recommended revisions to the WHO guidelines (Blumenthal et al., 2000). Considering stable performance and effective removal of bacterial indicators as well as other water quality parameters, low maintenance, and cost-effectiveness, wetland and pond systems were thought to be an effective and feasible alternative for wastewater treatment system for rural area.

Ⅳ. Conclusion

Our experimental study demonstrated that a SSF wetland could be useful to treat sewage in a small community without reducing mass retention, except for T-N, even in winter. Cold climate problems in wetland systems were not anticipated in Korea where air temperature in winter (December to February) is −0.2 ℃ on average, and only occasionally drops below −10 ℃; temperatures were −0.5 ± 0.24 ℃ during the study period. If relatively poor-quality wetland effluent did occur during winter, this could be further polished, and cold climate problems could be overcome by a subsequent pond system. The results of this study indicate that three months of storage in an intermittent-discharge pond could provide substantial water quality improvement. The upper layer of the pond water column became remarkably clear right after ice melt, and then varied with algal biomass after algae started to grow. Timing of the pond effluent discharge might be critical in pond water management, and partial discharge of upper layers of pond water in March appears to be most advantageous. After discharge of the pond in the spring, ponds could be operated in a continuous flow regime to remove nutrients and pathogens, and to provide water for crop irrigation. After further treatment using pond, the level of fecal coliform was less than WHO guidelines for wastewater reuse for crop irrigation, therefore pond effluent may be safely used for crop irrigation without risk of infection by sewage-borne pathogens. In this case the wetland is a primary and secondary treatment system, and also a tertiary treatment system or storage pond for crop irrigation.

Overall, the wetland system was found to be adequate for treating sewage in a small community in Korea. Its performance was consistent and mass retention was stable throughout the year. The intermittent-discharge pond was effective for further treatment of relatively poor-quality wetland effluent in winter. The reuse of pond effluent for crop irrigation recycles nutrients and water resources and reduces water quality problems in the receiving water. Therefore, a wetland and subsequent pond system is recommended as a practical alternative for treating sewage in small communities in Korea.

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References

1. APHA. 1998. *Standard Method for the Examination of Water and Wastewater*, 20th ed. Washington, D.C.: American Public Health Association.
2. Blumenthal, U. J., D. D. Mara, A. Peasey, G. Ruiz-Palacios, and R. Stott. 2000. *Guidelines for the microbiological quality of treated wastewater used in agriculture: recommendations for revising WHO guidelines*. WHO Bulletin 78(9). Geneva: World Health Organization.
3. Brodrichk, S. J., P. Cullen, and W. Maher. 1988. Denitrification in a natural wetland receiving secondary treated effluent. *Wat. Res.* 22 (4): 431-439.
4. Cooper R. C. and A. W. Olivieri. 1998. Infectious disease concerns in wastewater reuse. In *Wastewater reclamation and reuse*, ed. T. Asano, 489-520. Lancaster, PA: Technomic Publishing.
5. Feigin, A., I. Ravina, and J. Shalhevet. 1991. *Irrigation with Treated Sewage Effluent*. Verlag, Berlin, Heidelberg: Springer.
6. Gumbricht, T. 1992. Tertiary wastewater treatment using the root zone method in temperate climates. *Ecol. Eng.* 2 (1): 1-30.
7. Heaven, S., L. N. Pak, N. M. Kim, and D. J. Waters. 2002. Wastewater storage reservoirs in Kazakhstan: the Sorbulak system and the potential for waste stabilization ponds. In *Proc. 5th International IWA Specialist Group Conference on Waste Stabilization Ponds*, 715-722. Auckland, New Zealand: NZ Water & Waste Association.
8. Kadlec, R. H., and R. L. Knight. 1996. *Treatment wetlands*. Boca Raton, FL: Lewis Publishers.
9. Knight, R. L., T. W. McKim, and H. R. Kohl. 1987. Performance of a natural wetland treatment system for wastewater management. *J. WPCF*. 59: 746-754.
10. Kwun, S. K., C. G. Yoon, and I. M. Chung. 2001. Feasibility study of treated sewage irrigation on paddy rice culture. *J. Environ. Sci. Health* A36(5): 807-818.
11. Mara, D., and S. Cairncross. 1989. *Guidelines for the safe Use of wastewater and Excreta in Agriculture and Aquaculture*. Geneva: World Health Organization.
12. Newman, J. M., J. C. Clausen, and J. A. Neafsey. 2000. Seasonal performance of a wetland constructed to process dairy milk-house wastewater in Connecticut. *Ecol. Eng.* 14(1-2): 181-198.
13. Price, D. S., D. W. Smith, and S. J. Stanley. 1995. Intermittent-discharge lagoons for use in cold regions. *J. Cold Regions Engineering* 9 (4): 183-194.
14. Reed, S. C., and D. S. Brown. 1995. Subsurface flow wetlands-a performance evaluation. *Water Environ. Res.* 67(2): 244-248.
15. Tucker, C. S., S. K. Kingsbury, J. W. Pote, and C. L. Wax. 1996. Effects of water management practices on discharge of nutrients and organic matter from channel catfish (*Ictalurus punctatus*) ponds. *Aquaculture* 147: 57-69.
16. US EPA. 1983. Design manual: Municipal wastewater stabilization ponds, 75-146. EPA/625/183/015. Washington, DC: U.S. Environmental Protection Agency.
17. Wallace, S., G. Parkin, and C. Cross. 2001. Cold climate wetlands: design and performance. *Wat. Sci. Tech.* 44(11-12): 259-265.
18. Wittgren, H. B., and T. Mæhlum. 1997. Wastewater treatment wetlands in cold climates. *Wat. Sci. Tech.* 35(5): 45-53.