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Feasibility Study of Constructed Wetland System for Sewage Treatment in Rural Area

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ABSTRACT : Field experiment was performed from August 1996 to December 1999 to examine the feasibility of constructed wetland system for sewage treatment in rural areas. A pilot system was installed in Konkuk University and the effluent of septic tank for school building was used as an influent to the wetland treatment basin. The system was composed of sand and reed, and operated continuously including winter time. Average removal rate of about 70% was observed for BOD, COD, and SS, about 50% for T-P, and about 25% for T-N. The reason for poor T-N removal might be due to high loading rate and short retention time. The system demonstrated satisfactory effluent concentration and stable performance in growing season. And it also worked adequately in wintertime even below 10°C without freezing, and removal was still significant. The amount removed in BOD, COD, and SS was almost the same as in the growing season, and the amount removed in nutrients was about half of the one in growing season. Overall performance of the experimental system was compared with existing data base (NADB, 1994), and it was within the range of general system performance. As study period increased, removal rates for BOD, COD, SS, and T-P were consistently maintained and even enhanced, but removal rate for T-N decreased slightly. Wetland system was thought to be a feasible alternative for sewage treatment in rural area considering its low cost and low maintenance requirement. However, the effluent of the experimental wetland system often exceeded current effluent water quality standards, therefore, further treatment could be required if the effluent should be discharged to public waters. Wetland system of interest locates in rural area and is a part of rural ecosystem, therefore, ultimate disposal of reclaimed sewage for agricultural purpose or subsequent land treatment might be available and further research in this matter is recommended.

Key Words : Constructed wetland, Sewage treatment, Removal rates, Rural area, Influent and effluent, Pollutant concentration, Feasibility, Pilot study.

INTRODUCTION

Wastewater generated from rural housing had been naturally purified without environmental concern in Korea. In most rural community, the quantity of sewage was not significant and it had been disposed of to the surrounding empty lot. The housing pattern of the rural community changed with economic development, and the traditional farm villages with scattered housing were converted to modernized villages with relatively dense population. Development of small rural communities with about 50~100 houses has been practiced throughout the country as a part of national development project. Thus, generation of wastewater from rural community increased steadily, and it became a major pollutant source for water quality problem in receiving water bodies.

Comprehensive and complicated conventional wastewater treatment plants are not feasible to the small village in rural area. The quantity of wastewater from one village is too small to use conventional treatment methods, wastewater collection from neighboring villages is not practical because of geographical constraints, and operation of the treatment plants is not cost effective. Therefore, alternative wastewater treatment methods applicable to small rural villages should be developed.

More natural resources available in rural area for wastewater treatment than in urban area. Wastewater can be purified naturally if loading does not exceed assimilation capacity of natural resources. Natural resources like soil, water, and plants can be used for wastewater purification and their removal process is natural and does not generate secondary contamination. The soil-based systems include slow rate, rapid infiltration, overland flow, leach field, and absorption bed. The water-based systems include stabilization pond and their variations, aquatic units with floating plants, and wetland systems (WPCF, 1990).

Two types of wetland systems are available for wastewater treatment: surface flow system (SF) and subsurface flow system (SSF). Subsurface wetland system can be constructed with an objective of secondary or advanced treatment of wastewater, and has also been called "root zone" or "rock-reed filter" and consists of channels or trenches with relatively impermeable bottoms filled with sand or rock media to support emergent vegetation (Metcalf & Eddy, 1991).

Wetland system is a cost-effective and low technology based alternative, and can be applicable to the small wastewater treatment system in rural community (Lowe, 1990). Wetland systems become widely accepted for wastewater treatment, and the attractive basic functions of wetland systems are physical entrapment of pollutants through filtration and sorption in the surface soils and organic matter, utilization and transformation of elements by microorganisms, and low energy and maintenance requirements to attain consistent treatment levels (Kadlec, 1994; Hey, 1994). The most frequently used emergent plants in wetland systems include cattails, reeds, rushes, bulrushes and sedges. The major benefit of plants in wetland system is transferring of oxygen to the root zone. Reeds are tall annual grasses with an extensive perennial rhizome, and reeds are effective in oxygen transfer because the rhizomes penetrate vertically and more deeply (USEPA, 1988).

In this study, feasibility of the subsurface flow type of constructed wetland system which was consisted of sand and reed was examined to treat the domestic sewage. Field experiment was performed from August 1996 to December 1999 and the results are presented in this paper.

MATERIALS AND METHODS

A pilot wetland system was installed in Konkuk University and the effluent of septic tank for school building was used as an influent to the system. The treatment basin was 9m long, 2m wide, and 1.0m deep, and it was filled with sand in 0.6m deep where reeds were transplanted. The effluent of the septic tank was pumped to the storage tank, and it flowed to the treatment basin by gravity as shown in Figure 1. The wall and bottom of basin were built with concrete, and the bottom had 1% slope down to the outlet zone. The perforated 2"-ϕ pvc pipe surrounded by gravel was installed at the bottom of the outlet zone. The void ratio and specific gravity of the sand was 0.36 and 2.64, respectively. Actual treatment area and volume was 16m^2 (8m × 2m) and 9.6m^3 (8m × 2m × 0.6m),

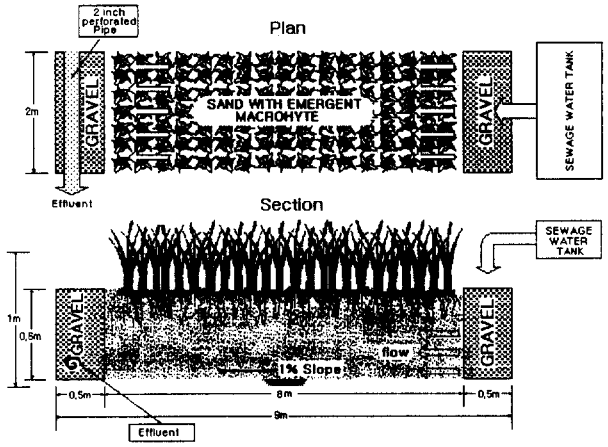

Fig. 1. Schematic plan and section of the constructed wetland system

respectively. Two hydraulic loading rates were applied. From August 1996 to June 1998 the hydraulic loading rate was fixed with about 15.63cm/day and theoretical detention time was 1.38 days, and from July 1998 to December 1999 the hydraulic loading rate was about 6.25cm/day and theoretical detention time was 3.5 days.

The influent and effluent were sampled with time lag of hydraulic detention time to evaluate the removal efficiency of the system. The concentrations of influent and effluent were analyzed for the conventional pollutants: BOD, COD, SS, T-N, and T-P. Standard Methods (APHA, 1995) was used to analyze the constituents, and specific methods used are summarized in Table 1. Total nitrogen was calculated by T-N = TKN + NO_2^--N + NO_3^--N.

Table 1. Analytical methods used for constituents

Constituents	Methods*	Remark
DO (dissolved oxygen)	SM(standard method) 4500-O C	Azide Modification Method
BOD (biochemical oxygen demand)	SM 5210-B	5-day BOD test
COD (chemical oxygen demand)	SM 5220-B	$K_2Cr_2O_7$ used
SS (suspended solids)	SM 2540-D	
T-N (total nitrogen)		
Organic nitrogen	SM 4500-N_{org}-C	
NH_3-N	SM 4500-NH_3-D	BÜCHI 435 and B-316
NO_2-N	SM 4110-B	Dionex DX-100
NO_3-N	SM 4110-B	Dionex DX-100
T-P (total phosphorus)	SM 4500-P E	HP8452A Spectrophotometer

* SM : Standard Methods

RESULTS AND DISCUSSION

Constituents removal

The influent and effluent of the constituents are shown in Figure 2. The influent DO concentration was very low because it was pumped from the septic tank where anaerobic condition prevails, however, the effluent DO concentration increased with average of 2.1 mg·L^{-1} without aeration as shown in Figure 2. It implies that oxygen supply from the atmosphere and roots were enough to keep the system aerobic.

The influent BOD concentration varied widely from 24 to 345 mg·L^{-1} with average of 131 mg·L^{-1}. The effluent BOD concentration was significantly lower than the influent ranging from 5 to 189 mg·L^{-1} with average of 40 mg·L^{-1} as shown in Figure 2, but it often exceeded water quality standard of 20 mg·L^{-1}. The average removal rate of BOD was about 72%.

As shown in Figure 2, the COD performance was similar to that of BOD. The influent COD concentration was between 51 and 460 mg·L^{-1} with average of 220 mg·L^{-1}, and the effluent COD concentration was between 10 and 275 mg·L^{-1} with average of 76 mg·L^{-1}. The average removal rate of COD was about 64%. Figure 2 illustrates that the system reduced BOD and COD consistently throughout the study period. Organics might be, for the most part, degraded aerobically by microorganisms attached to plants and sediment. However, anaerobic degradation could in some cases be significant. The oxygen needed to support the aerobic processes is supplied directly from the atmosphere via diffusion through the sediment or water-atmosphere interface, by photosynthetic oxygen production within the water column, and by oxygen leakage from macrophyte roots. Anaerobic degradation may occur during periods with oxygen depletion in the water column and in anaerobic sediments (Moshiri, 1993). The wetland system was thought to be effective and consistent to remove organics.

The influent SS concentration was 9~176 mg·L^{-1} as shown in Figure 2, however, the effluent SS concentration was far lower with average of 17 mg·L^{-1} and average removal rate was about 71%. It was demonstrated that the subsurface flow type wetland system is quite effective in removing solids. It make sense because the wetland system was filled with sand and suspended solids would be filtered out effectively. These physical filtration process also removes a significant proportion of other wastewater constituents.

The performance data for nutrients was less satisfactory than the others. The influent T-N concentration was higher than normal domestic wastewater. The reason was that the wastewater used in the experiment was generated from the school building where toilet wastewater prevailed and other drain-water was not included. The influent T-N concentration was 20~225 mg·L^{-1} with average of 111 mg·L^{-1}, and effluent was 18~180 mg·L^{-1} with average of 85 mg·L^{-1}. The average removal rate was about 21%, and the performance was not consistent and sometimes the effluent exceeded the influent as in Figure 2. The major removal mechanism for nitrogen in wetland system is nitrification-denitrification. Ammonia is oxidized to nitrate by nitrifying bacteria in aerobic zones, and nitrates are converted to nitrogen gas (N_2) by denitrifying bacteria in anoxic zones. Nitrogen is also taken up by the plants and incorporated into the biomass. Plant uptake of nitrogen is, however, generally of less important than denitrification. Generally, five days are recommended for proper removal of nitrogen, but shorter detention time of this study might cause poor performance in addition to abnormally high influent concentration. If the system was operated with normal strength of wastewater and enough detention time, better performance could be expected.

The average influent and effluent T-P concentrations was 18 mg·L^{-1} and 8 mg·L^{-1}, respectively, as shown in Figure 2, and the removal rate was about 50% which was greater than in T-N. Phosphorus removal in wetland system occurs mainly as a consequence of adsorption, complexation, and precipitation reaction with aluminum (Al), iron (Fe), Calcium (Ca), and clay minerals in the sediment. Alternate wet and dry periods enhance the fixations of phosphorus in the sediments (Moshiri, 1993).

The adsorption is not an ultimate removal process, and it can be accumulated in the soil zone after soil particle surfaces saturated as phosphorous loading rate exceeds the assimilation capacity of the wetland system. Then, adsorption process is expected to be ineffective, and instead desorption can even increase the phosphorous concentration in the effluent. In this study, phosphorus removal efficiency in wetland system was still not affected after about 4-year operation. The assimilation capacity and life time of designed wetland system should be carefully examined for full scale operation.

Winter and growing season performances

The study was performed including winter time where removal efficiency was generally thought to be minimal. The system worked without freezing even under -10°C of air

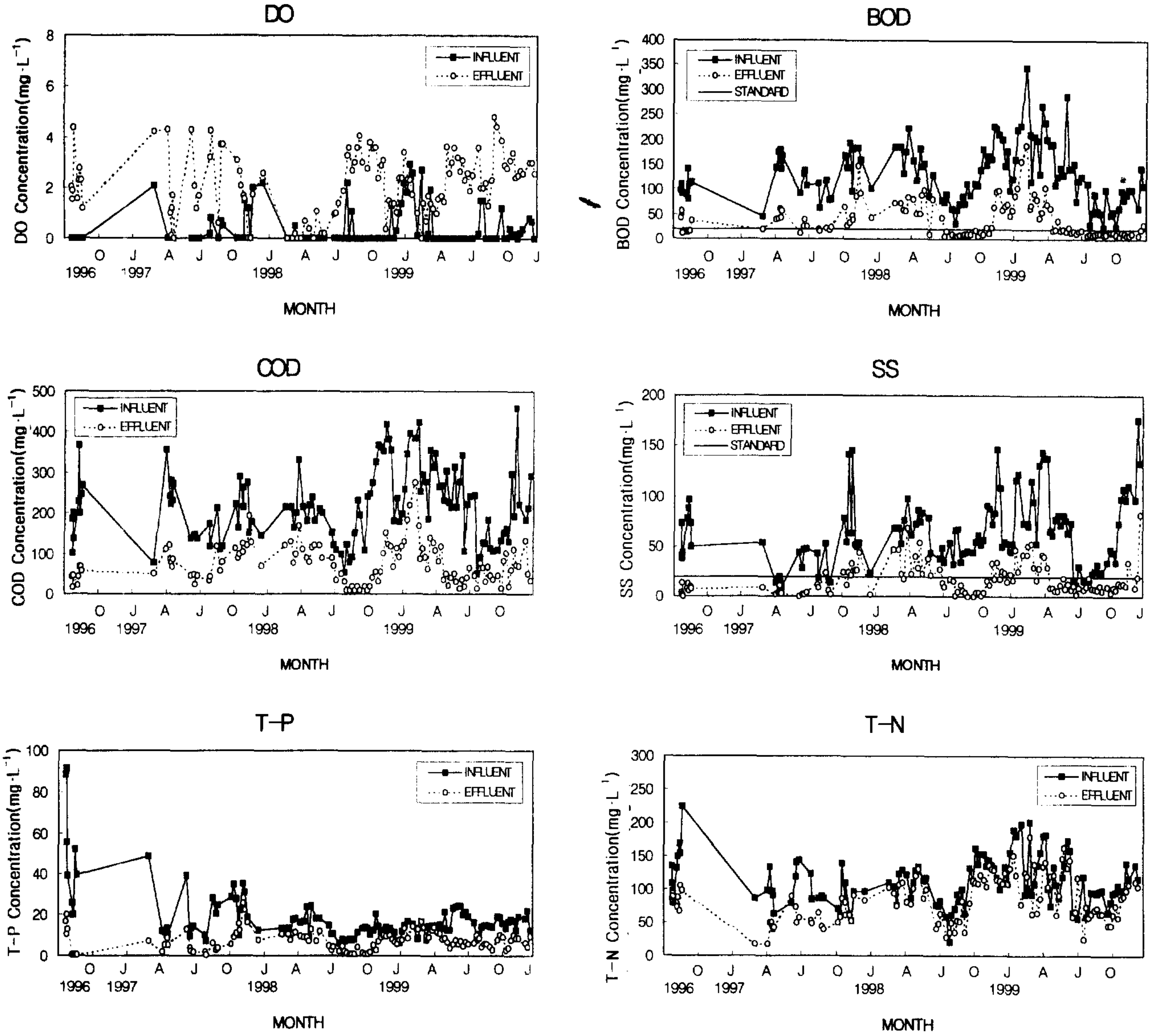

Fig. 2. Influent and effluent data of the wetland system

temperature as long as wastewater was flowing. The summary of performances in growing season and winter is shown in Table 2. The average removal rates of constituents in winter were lower than the one in growing season, however, removal performance during winter was still significant.

The amount of BOD removed in winter was almost same as in the growing season. SS removal rate was less affected by temperature, but lower decay during the winter can result in accumulation of the SS in the system and its releasing in next spring could affect whole system performance. The winter removal rates of nutrients like T-N and T-P were decreased about in half compared to the growing season due to absence of the plant uptake and limited decomposition by microorganism.

Generally, the wetland system was thought to be adequate for rural sewage treatment. However, winter performance was concerned and measures for subsequent management of wetland effluent should be further studied. Considering characteristics of rural environment, further natural purification by disposal to large farmland or forest area in proper way rather than discharge to public water body is recommended.

Loading rate and effluent

Experimental data was compared with existing wetland performance data (NADB, 1994), and the system performance was within the range as shown in Figure 3. Generally, the loading rates for constituents of this study were in high margin

Table 2. Comparison of performances in growing season and winter

Component \ Period		Growing season	Winter
Hydraulic loading ($cm \cdot day^{-1}$)		6.25	6.25
Hydraulic retention time (days)		3.50	3.50
BOD	Loading rate ($kg \cdot ha^{-1} day^{-1}$)	93.29	136.50
	Avg. removal Rate (%)	77.7	50.90
	Amount removed ($kg \cdot ha^{-1} day^{-1}$)	72.49	69.48
SS	Loading rate ($kg \cdot ha^{-1} day^{-1}$)	46.43	52.86
	Avg. removal rate (%)	72.70	62.80
	Amount removed ($kg \cdot ha^{-1} day^{-1}$)	33.75	33.20
T-P	Loading rate ($kg \cdot ha^{-1} day^{-1}$)	8.44	9.87
	Avg. removal rate (%)	48.00	20.60
	Amount removed ($kg \cdot ha^{-1} day^{-1}$)	4.05	2.03
T-N	Loading rate ($kg \cdot ha^{-1} day^{-1}$)	77.41	92.50
	Avg. removal rate (%)	19.20	11.00
	Amount removed ($kg \cdot ha^{-1} day^{-1}$)	14.86	10.18

and nutrient loading rates were in upper limit of the range. The T-N loading was high, and its resulting effluent concentration was also high with poor removal rate. From the scatterplot of existing data, the system might be able to meet the water quality standards if loading rates had been low.

The scatterplot of effluent concentration versus loading rate embodies the key variables associated with wetland design: influent concentration, hydraulic loading, and effluent concentration. It can be useful to estimate loading rate for the expected operation conditions, and can be used as a guideline for wetland design at planning stage. However, well organized pilot study is necessary for full scale application.

Removal efficiency with time

Average removal rates of each year are summarized in Table 4. Experimental data of the second year was not complete, therefore, removal rates only for growing season were compared to examine aging effect of wetland system.

As operation continued, BOD and COD removal rates increased, SS and T-P removal rates were less influenced, but T-N removal rates decreased gradually. The reason for better removal of BOD and COD might be that wetland system became stabilized and more adjusted microorganisms decomposed organic pollutant in the system effectively. The study period was less than 4 years and there was no apparent deterioration observed in wetland performance except T-N which was not normal as mentioned above. From the limited data obtained in this study, wetland aging effect may not be significant for organic and solid removals if not excessively loaded. However, accumulation of phosphorus and nitrogen could be concerned for the life time of wetland system. Therefore, adequate management and careful monitoring of the system might be required for proper operation.

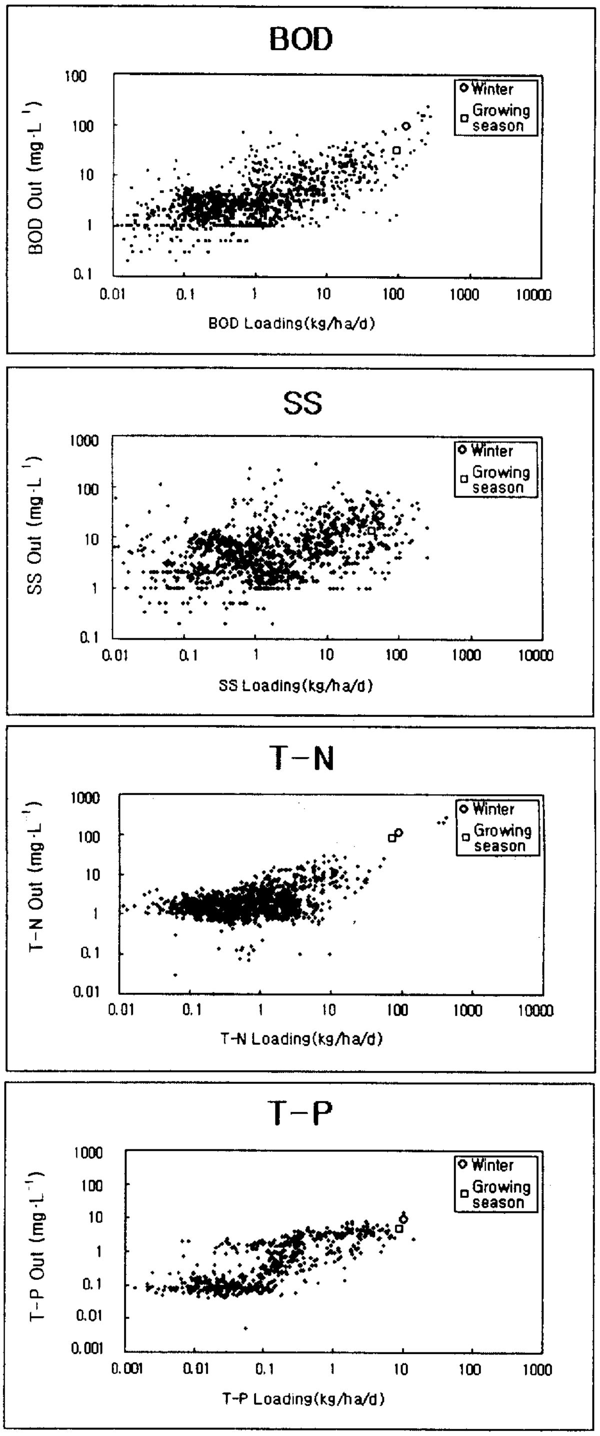

Fig. 3. Scatterplots of wetland performance (NADB, 1994)

Table 4. Yearly wetland performance data for constituents

		Average concentration ($mg \cdot L^{-1}$)			Average removal rate (%)		
		2nd year	3rd year	4th year	2nd year	3rd year	4th year
BOD	Influent	136.0	123.3	115.7	72.4	75.1	81.1
	Effluent	38.2	33.4	21.1			
COD	Influent	206.4	201.1	216.8	60.1	67.8	70.0
	Effluent	80.9	60.6	59.2			
SS	Influent	44.3	60.4	62.8	74.1	71.3	72.9
	Effluent	10.8	17.9	13.3			
TP	Influent	18.9	13.5	16.6	57.3	60.2	53.1
	Effluent	7.4	5.7	7.4			
PO_4-P	Influent	5.7	7.4	9.2	64.3	57.7	52.9
	Effluent	2.7	3.3	4.3			
TN	Influent	98.4	105.3	110.4	39.9	23.3	22.3
	Effluent	55.5	83.4	84.0			
TKN	Influent	94.7	104.4	110.0	49.6	28.4	30.3
	Effluent	44.7	78.0	76.2			
Org.-N	Influent	5.1	9.3	6.5	48.7	56.9	69.7
	Effluent	2.5	4.5	1.7			
NH_3-N	Influent	89.6	95.2	103.6	49.6	26.0	29.7
	Effluent	42.2	73.5	74.5			
NO_2-N	Influent	2.6	0.0	0.0	-	-	-
	Effluent	2.1	0.1	0.1			
NO_3-N	Influent	1.1	0.8	0.4	-	-	-
	Effluent	8.7	5.3	7.7			

(2^{nd} year : '97.4 ~ '97.11; 3^{rd} year : '98.4 ~ '98.11; 4^{th} year : '99.4 ~ '99.11)

CONCLUSIONS

Field experiment was performed to examine the applicability of constructed wetland system for rural sewage treatment, and the results can be summarized as below.

1. Average removal rate of about 70% was obtained for BOD, COD, and SS, about 50% for T-P, and about 25% for T-N. Generally, the system worked well to treat sewage, and its performance was within the range of existing data base.
2. The system also worked adequately in wintertime even below 10°C without freezing, and removal was still significant. The amount removed in BOD, COD, and SS was almost the same as in the growing season although removal rates were relatively low.
3. From the limited data obtained in this study, wetland aging effect may not be significant for organic and solid removals if not excessively loaded. However, accumulation of nutrients could be concerned for the life time operation of wetland system. Therefore, adequate management and careful monitoring of the system might be required for proper operation.
4. Wetland system was thought to be a feasible alternative for sewage treatment in rural area considering its low cost and low maintenance requirement. However, the effluent of the experimental wetland system often exceeded water quality standards, and subsequent treatment could be required if the effluent should be discharged to public waters. Wetland system of interest locates in rural area and is a part of rural ecosystem, therefore, ultimate disposal of reclaimed sewage for agricultural purpose or subsequent land treatment might be available and further research in this matter is recommended.

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