

Performance of Constructed Wetland for Nutrient Removal of Agricultural Drainage

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ABSTRACT

Fresh water bodies in Japan have been receiving increased attention owing to nutrient pollution caused by agricultural activities from its surroundings. A study was carried out to estimate nitrogen and phosphorus flows and, with the estimated results, develop a model to simulate water purification in the constructed wetland. The study site is located in the Nishinoko Basin at the lower reach of the Shyounaka reclaimed land. The wetland receives agricultural drainage water mainly from paddy fields. Nishinoko is interlinked with Lake Biwa, the largest lake in Japan. With the use of automatic water level sensors, inflow and outflow of the wetland were monitored from April 2009 to February 2010. During the same period, to estimate nitrogen and phosphorus loadings, water samples were taken for water quality analysis. The results showed that 30 and 10% of nitrogen and phosphorus, respectively in the drainage were removed by the wetland. The system dynamics model was then developed for simulation of nitrogen flow and used a wetland management tool to identify better management strategies under the current circumstances. The simulation outputs showed good agreement with measured flow and loadings. The sensitivity analysis of the model indicated that the nitrogen removal coefficient represents the degree of water purification capacity as the most sensitive parameter.

Key words: Agricultural drainage, Constructed wetland, Nitrogen, Phosphorus

INTRODUCTION

Nutrient enrichment has become the most widespread water quality problem in the world, which is most often associated with nitrogen and phosphorus from agricultural runoff (UNEP, 2010). As one of the water treatment measures, construction of artificial wetlands to receive agricultural drainage has received increased attention because of its ability to reduce eutrophication materials, such as nitrogen and phosphorus, in water bodies with relatively low operation and maintenance costs (Shimatani et al., 2003). Researches have been performed in the past for better understanding water purification capacity of wetlands related to hydrology, transformation, and crop absorption properties, and simulation models have been developed and tested under various conditions (such as Edelfeldt and Fritzson, 2008; Martin, 1997; Mayo and Mutamba, 2005; Spieles and Mitsch, 2000). The present study is aimed at assessing the characteristics of the water purification capacity of the constructed wetland and developing the model to simulate wetland nitrogen flow.

MATERIALS AND METHODS

Study location

Yoshikirinoike was selected as the wetland for this study. It is constructed on the east side of the Nishinoko lake in the Shiga Prefecture, Japan, in order to reduce the amount of nutrient loading from the Syounakanoko polder of 342 ha prior to flowing into the Nishinoko. The Nishinoko is interconnected with Lake Biwa. The Lake Biwa was registered in 1993 as a Ramsar wetland site, and its area was expanded to include the Nishinoko in 2008, while efforts have been made for

conservation of water environment in those lakes (Aburatani et al., 2009; Nishino and Hamahashi, 2005). Rice is the main crop grown in the polder and is normally planted in late April or early May and harvested in September or October. The wetland has a surface area of 20000 m² with an average depth of 2 m. The hydraulic retention time is approximately two days. *Phragmites australis* and *Iris pseudacorus* L. have been planted in the wetland to enhance nutrient removal.

Measurements

In the development of the model, the estimation of loadings and calibration, inflow and outflow of the wetland and their concentrations of total nitrogen (T-N) and total phosphorous (T-P) were measured from April 2009 to February 2010. Water samples were collected twice a month during the irrigation period (May-September 2009), once a month during the non-irrigation period (October 2009-February 2010), and every day during the land preparation period (April 2009). For the flow monitoring, the automatic water level sensors were installed in outflow and inflow water courses of the wetland. Concentrations of T-N and T-P in the samples were analyzed by using the photo-spectrometer. The inflow and outflow loadings were estimated by multiplying measured T-N and T-P concentrations by measured flows. Figure 1 shows the aerial photograph of the study area.

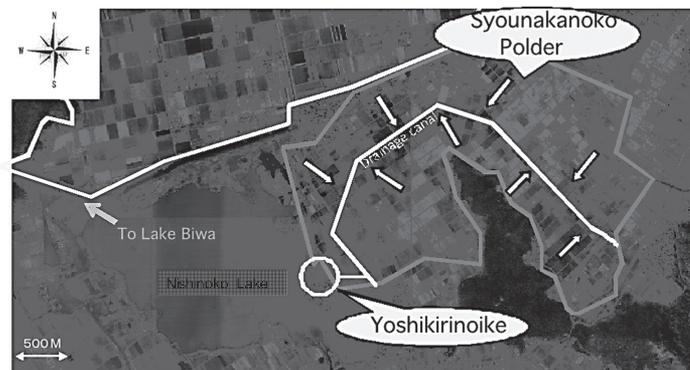


Figure 1. Study area showing Yoshikirinoike, Syounakanoko polder, and Nishinoko.

Model calibration

The model was written in STELLA™ (Richmond et al., 1987), and its structure was followed by that of the wetland model developed by Spieles and Mitsch (2000). The model consists of material flow and water flow sub-models. For the material flow, nitrogen was the only concern in the model. The input parameters for the estimation of the water budget were inflow, rainfall, outflow, evapotranspiration, and infiltration. The rainfall and evapotranspiration data were obtained from the Hikone meteorological station, the nearest station from the study site. The major input parameters for the estimation of the material flow were inflow loading, water depth of the wetland, and water temperature. The STELLA™ model diagram referring Spieles and Mitsch (2000) is shown in Figure 2, and the model equations, parameters, and their values are shown in Table 1. The amount of nitrogen removal was estimated by adapting removal and infiltration coefficients in the calibration.

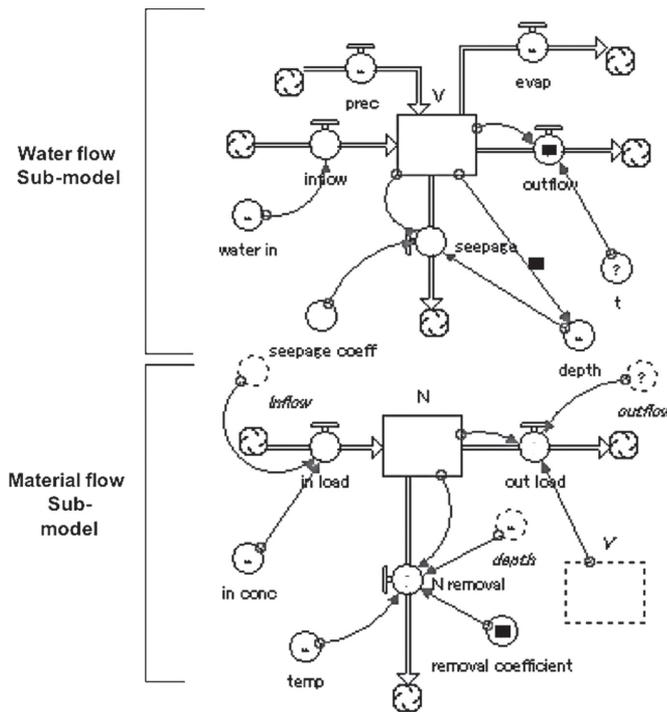


Figure 2. Developed model diagram for simulation of water and material flows.

Table 1. Model equations and parameters based on Spieles and Mitsch (2000) and their values.

Water flow: $\frac{dV}{dt} = Q_{in} + P + Q_{out} - ET - \left(\frac{V}{d}\right) \times I$ Material flow: $\frac{dN}{dt} = Q_{in} + C_{in} - \frac{(N \times Q_{out})}{V} - N \times (k \times \frac{\bar{d}}{d}) \times f(T)$		
Inflow (Q_{in})	m ³ /day	Measured data
Inflow N concentration (C_{in})	kg/ m ³	
Evapotranspiration (ET)	m ³ /day	
Precipitation (P)	m ³ /day	
Average wetland water depth (\bar{d})	2.0 m	
Infiltration (I)	0.18 m/day	Calibration
Nitrogen removal coefficient (k)	0.17/day	
Temperature function: $f(T)$	$1.1^{(T-20)}$	Measured water temperature (T)
Nitrogen mass in the wetland (N)	50 kg	Initial value
Water volume in the wetland (V)	17000 m ³	
Outflow (Q_{out})	m ³ /day	Simulation
Outflow N concentration (C_{out})	kg/m ³	

RESULTS AND DISCUSSION

Loading estimation from field data

Table 2 shows measured average T-N and T-P concentrations of inflow and outflow during the different periods. It was observed that there were slightly higher concentrations during the land preparation period compared to those in the irrigation and non-irrigation periods. Table 3 shows estimated average T-N and T-P loadings of inflow and outflow during the different periods. The results showed that 30 and 10% of T-N and T-P, respectively, in the drainage were removed from the wetland.

Table 2. Average T-N and T-P concentrations of inflow and outflow during the different periods.

Period	T-N (mg/l)		T-P (mg/l)	
	Inflow	Outflow	Inflow	Outflow
Land preparation	2.47(1.27)	2.31(0.66)	0.53(0.08)	0.36(0.04)
Irrigation	2.24(0.36)	1.52(0.04)	0.35(0.05)	0.30(0.03)
Non-irrigation	1.85(0.043)	2.21(0.68)	0.31(0.00)	0.23(0.11)
Entire study period	2.08(0.41)	1.84(0.60)	0.34(0.06)	0.27(0.09)

Note: Numbers in parentheses are standard deviations.

Table 3. Average T-N and T-P loadings of inflow and outflow during the different periods.

Period	T-N (kg/day)		T-P (kg/day)	
	Inflow	Outflow	Inflow	Outflow
Land preparation	22.12(7.27)	19.65(0.90)	5.40(2.80)	3.32(1.25)
Irrigation	18.64(0.55)	13.57(0.89)	3.05(0.85)	2.97(0.94)
Non-irrigation	0.75(0.10)	0.29(0.78)	0.13(0.00)	0.02(0.12)
Entire study period	11.00(9.3)	7.69(6.67)	1.86(1.71)	1.67(1.19)

Note: Numbers in parentheses are standard deviations.

Model development

In the water flow sub-model, the result of the model calibration showed that a high correlation was obtained between simulation and measured values (Figure 1), given by the least square equation of $Y = 0.97X$ with $R^2 = 0.97$ where X is the simulated value and Y is the measured value. The average measured and simulated outflows were $4408 \text{ m}^3/\text{day}$ and $4574 \text{ m}^3/\text{day}$, respectively. The material flow sub-model also achieved a reasonable outcome as $Y = 0.96X$ with $R^2 = 0.96$ (Figure 2). The average measured and simulated outflow loadings were 7.82 and 7.33 kg/day , respectively.

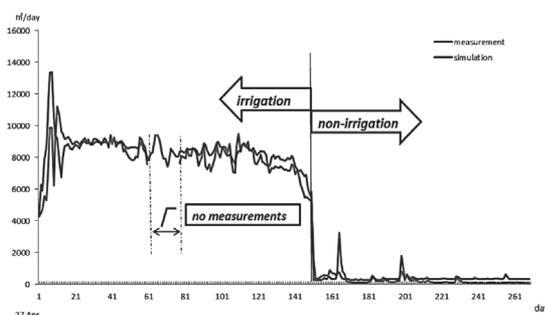


Figure 1. Comparison of simulated and measured outflows from the wetland.

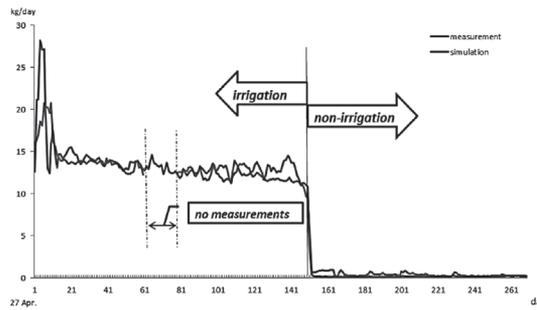


Figure 2. Comparison of simulated and measured outflow loadings from the wetland.

After calibration, the sensitivity analysis was performed by varying parameter values of the average wetland water depth (\bar{d}), the nitrogen removal coefficient (k), and the water temperature (T). The result showed k as the most sensitive parameter. Table 4 shows the result of the sensitivity analysis by changing k values.

Table 4. Difference in simulated average outflow loading (kg/day) by changing the nitrogen removal coefficient (k) value.

K value	0.1	0.2	0.3	0.4	0.5	0.6
Entire period	4.67	6.83	8.13	9.02	9.65	10.14
Irrigation period	7.62	11.43	13.74	15.31	16.45	17.31
Non-irrigation period	0.89	0.94	0.95	0.96	0.96	0.97

CONCLUSION

This study estimated T-N and T-P removals of agricultural drainage water through the constructed wetland. The results showed 30% of T-N and 10% of T-P removals in average from the wetland. The other studies showed variable values of removal rates under various conditions that ranges from 25 to 75% in case of T-N, and the study site seems to have a potential to increase the removal capacity by improving its operation and management. The study also demonstrated that the developed model could reasonably simulate the water and material flows of the wetland and applicable as a wetland management tool for the study site. This study continues as the model is going to be improved and validated using the data collected during 2010 and 2011. The improved model is expected to simulate the transformation process of nitrogen and take account of the process of plant uptake in more detail so that it enables to simulate the nitrogen removal process more precisely under various climates, inflow rates, and plant densities of the wetland.

REFERENCES

Aburatani, N., Y. Matsuno, S. Ochi, and N. Hatcho. 2009. A study on the material cycle of Nishinoko basin in the east coast of Biwako. Annual Report of the Institute of Resource Recycling of Kinki University 7: 37-43. (in Japanese)

Edelfeldt, S., and P. Fritzon. 2008. Evaluation and comparison of models and modelling tools simulating nitrogen processes in treatment wetlands. Simulation Modelling Practice and Theory 16(1): 26-49.

Martin, J. 1997. Interaction and spatial distribution of wetland nitrogen processes. Ecological Modelling 105(1): 1-21.

- Mayo, A.W., and J. Mutamba. 2005. Modelling nitrogen removal in a coupled HRP and unplanted horizontal flow subsurface gravel bed constructed wetland. *Physics and Chemistry of the Earth, Parts ABC* 30(11-16): 673-679.
- Nishino, M., and E. Hamabata. 2005. Messages from Naiko: conservation of the biodiversity in the wetland around Lake Biea and its rehabilitation Press, Shiga. (in Japanese)
- Richmond, B., S. Peterson, and P. Vescuso. 1987. An academic user's guide to STELLA™. High Performance Systems, Inc., Lyme, NH.
- Shimatani, Y., M. Hosomi, and K. Nakamura. 2003. Water quality treatment of rivers and lakes by eco-technologies—conservation and restoration of sustainable water environment. Soft Science Company, Japan. (in Japanese)
- Spieles, D. J., and W. J. Mitsch. 2000. The effects of season and hydrologic and chemical loading on nitrate retention in constructed wetlands: a comparison of low- and high-nutrient riverine systems. *Ecological Engineering* 14: 77-91.
- UNEP. 2010. Clearing the waters: A focus on water quality solutions. United Nations Environment Programme. Nairobi, Kenya.