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ORIGINAL ARTICLE

Water Quality Simulation of the Reservoir Using Ecological Model

Dong-Myung KIM[1)*], Ji-Won SUK[1)], Sun-Young KIM[1)], Sang-Ik SHIN[2)], Kyong-Joon ROH[3)]

[1)]*Department of Ecological Engineering, Pukyong National University, Busan 608-737, Republic of Korea*
[2)]*College of Marine Science, University of South Florida, St. Petersburg, Florida 33701, USA*
[3)]*Department of Environmental Engineering, Pukyong National University, Busan 608-737, Republic of Korea*

Abstract

Water quality of the Koejong-reservoir was estimated by using the ecological model to evaluate the effects of industrial sewage discharge. State variables consist of POC, DOC, phytoplankton, DIP, DIN, DO and COD. Initial conditions for the compartment are applied to the model based on the observed results. The reproducibility was found to be satisfactory with the relative error ranging between the calculated value and the observed value. Water quality simulation was conducted by applying additional industrial sewage discharge into the Koejong-reservoir. The concentrations of COD, Chl.a, DIP and COD showed fluctuations of a narrow range. The increment percentages of Chl.a, COD and DIP were 26.6%, 20.2% and 18.2%, respectively. In the case of DO, the concentration decreased 4.8%.

Key words : Ecological model, Reservoir, Water quality, Pollution, Simulation

1. Introduction

Except for the man-made lakes or reservoirs nearby the big rivers, the ecosystem of lakes and reservoirs in Korea consist mostly of small lakes and reservoirs with shallow depth, which are easily influenced by the pollution sources in the basin zone. Since 1990, the majority of agricultural reservoirs have been showing eutrophication cause by the inflow of phosphorus and nitrogen from the watershed. The reservoir ecosystem has been disturbed by the increased productivity and bloom of phytoplanktons. Especially, the ecosystem of the man-made lakes and agricultural reservoir ecosystem in southwestern region of Korea is influenced by intensive farming and changes in of the waterside habitual environment accelerated by industrialization (Seo, 1978; La et al., 2008).

The natural phenomena taking place in the environment are extremely complicated, it is difficult to figure them all out exactly by research concentrated in a single field of study. The interdisciplinary model plays an important role as a tool to study, investigate and combine various information collected from a number of disciplines. The modeling process enables us to grasp the phenomena taking place in the study area, prioritize the research procedures, and plan the necessary data collecting. Prediction is another useful role of the model. When it is impossible to experiment on the natural environment directly, the model can be

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***Corresponding author** : Dong-Myung KIM, Department of Ecological Engineering, Pukyong National University, Busan 608-737, Republic of Korea
Phone: +82-51-629-6545
E-mail: dmkim@pknu.ac.kr

a useful tool.

Since it is very difficult to predict the advection and diffusion of contaminants in the reservoir, we use an ecological model in this study of Koejong-reservoir, which is capable of presenting the mechanism of biochemical reactions as well as the macroscopic cycle of nutrients in the reservoir. Ecological model is comprehensive analysis of ecology study and has different character from the model which is based on physical principle as a hydrodynamic model.

Koejong-reservoir is located in Goseong-gun, Gyeongsangnam-do, Korea. The runoff from the mountains flows into this reservoir, which is linked to Jangjeon-reservoir with a water channel. Wastewater discharge from industrial facilities, plants and houses surrounding the reservoir is the major input sources to the reservoir. Additional discharge of wastewater from the recently developed industrial complex in the vicinity of Koejong-reservoir is aggravating the freshwater region pollution, raising a concern for the reservoir ecosystem. We need to evaluate the water quality and the environmental changes caused by the water pollution.

Therefore, the purpose of this study is to measure the effect of the pollution load by additional discharge on the reservoir by using the ecological model.

2. Materials and Methods

2.1 Modeling system

For the total approach to the ecosystem, it is necessary to use the ecological model including the cycle of phosphorus and nitrogen which determine the photosynthesis of phytoplanktons in the aquatic ecosystem. The ecological model was developed by Kremer and Nixon(1978), and it was improved for the coast environment by Choi et al.(1994) and Kim et al.(1994). It has been used to estimate the environmental capacity and primary production ecosystem in Jinhae Bay and Masan Bay, Korea.

Fig. 1 presents a model written by using numerical modeling program. The cycles of carbon, nitrogen and phosphorus and the connection of phytoplanktons and dissolved oxygen in the ecological model are presented.

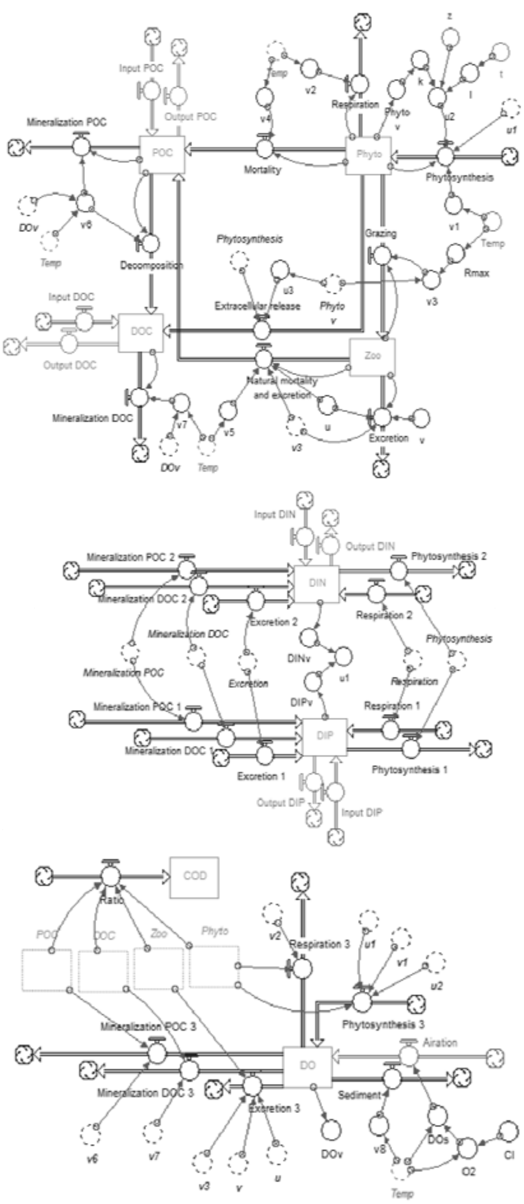

Fig. 1. The simulation diagram in the model.

2.2 Ecological model

This model system was constructed as a box model based on the model which has been applied by Nakata et al.(2000), Taguchi et al.(1998; 2009) for the lake ecosystems, and it has also been applied to the marine ecosystems by Sohma et. al.(2008), Choi et al.(1994), Kim et al.(2002), Hong et al.(2007), Kim et al.(2007), Hong et al.(2008).

The ecological model consists of phytoplankton (P), detritus(POM), dissolved organic matter(DOM), dissolved inorganic phosphorus(DIP), dissolved inorganic nitrogen(DIN), dissolved oxygen(DO) and chemical oxygen demand(COD).

Equation (1) describes the biomass B of compositions at a random site of the lake in the ecological model.

$$\frac{\partial B}{\partial t} = -u\frac{\partial B}{\partial x} - v\frac{\partial B}{\partial y} - w\frac{\partial B}{\partial z}$$

the term describing the transport by the tide and residual flow

$$+\frac{\partial}{\partial x}\left[Kx\frac{\partial B}{\partial x}\right] + \frac{\partial}{\partial y}\left[Ky\frac{\partial B}{\partial y}\right] + \frac{\partial}{\partial z}\left[Kz\frac{\partial B}{\partial z}\right]$$

the term describing the mixture by turbulent diffusion

$$+\frac{dB}{dt}$$

the term describing the biological and chemical process Equation (1)

Here, x, y and z are coordinates, t is time, u, v and w are the velocity components of x, y and z direction, Kx, Ky and Kz are eddy diffusivity of x, y and z direction, B is the biomass of components, dB/dt is the variation of components per time unit by biochemical process. Also, the calculating section of substance transport by advection is included in the diffusion equation. The velocity was applied to the ecological model to calculate the changes in the biomass B.

Table 1. The numerical formulation of the simulation

Phyto(t) = Phyto(t-dt)
+ Photosynthesis - Extracellular release – Respiration - Grazing – Mortality1
Zoo(t) = Zoo(t-dt)
+ Grazing - Mortality and excretion(scat) - Excretion(urine)
POC(t) = POC(t-dt)
+ Mortality 1 + Mortality 2 + Excretion Z1
- Mineralization of POC - Decomposition + (Input loads – Output loads)
DOC(t) = DOC(t-dt)
+ Decomposition + Extracellular release - Mineralization + (Input loads – Output loads)
DIP(t) = DIP(t-dt)
- Photosynthesis 1 + Respiration 1 + Excretion 1
+ Mineralization POC 1 + Mineralization DOC 1
DIN(t) = DIN(t-dt)
- Photosynthesis 2 + Respiration 2 + Excretion 2
+ Mineralization POC 2 + Mineralization DOC 2
DO(t) = DO(t-dt)
+ Photosynthesis 3 + Aeration - Respiration 3 – Excretion 3
- Mineralization POC 3 - Mineralization DOC 3 - Sediment
COD(t) = [COD : Cp]*(dP/dt) + [COD : Cz]*(dZ/dt)
+ [COD : Cpom]*(dPOC/dt) + [COD : Cdom]*(dDOC/dt)

Table 2. Initial condition for compartments in the ecological model

Initial condition for compartments							
Temp	DO	COD	DIP	DIN	POC	DOC	PHYTO
℃		(	㎎/L	)		(㎎-C/㎥)	
7.67	8.88	3.47	0.011	0.827	1403.0	2104.5	613.7

State variables consist of phytoplankton(P), zooplankton(Z), particulate organic carbon(POC), dissolved organic carbon(DOC), dissolved inorganic phosphorus(DIP), dissolved inorganic nitrogen(DIN), dissolved oxygen(DO) and chemical oxygen demand (COD). Table 1 presents the numerical formulation of the process in this model.

3. Results and discussion

3.1 Study area and input data

The study area is Koejong-reservoir located in Goseong-gun, Gyeongsangnam-do, Korea (Fig. 2). This study area is surrounded by warehouses, plants and houses, and construction of a new industrial facility is being planned. Thus, wastewater discharged from the new industry facility can be an additional input pollution source to the study area. Therefore, analysis of the water quality of the study area was conducted by using the ecological model. The initial condition for the compartments in the ecological model was based on the observed value at the study area (Table 2).

The total flux was estimated from the original sources of pollution that flows into the reservoir from the warehouses, plants and houses. The BOD discharge concentration was assumed to be 20mg/L of discharge water quality standard. Thus, in the original discharge loads, BOD is estimated at 0.61kg/day and T-P is 0.123kg/day. The additional input pollution source to the study area is the sewage discharge from the industry facility, and the sewage flow rate was estimated at 22.0m^3/day. BOD discharge loads were estimated at 0.11kg/day, and for T-P, 0.044kg/day (Table 3).

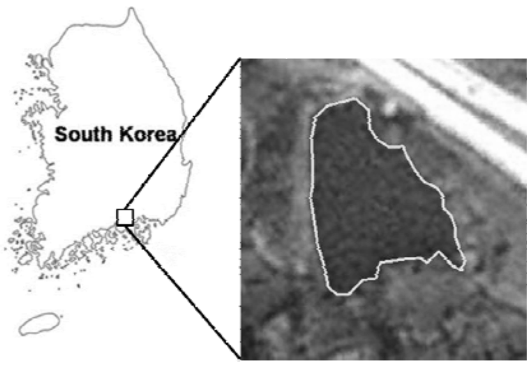

Fig. 2. The site map of the study area.

The parameters used in the model are derived from the thesis of Jorgensen et al.(2000), Nakata et al. (2000), Sohma et al.(2008), Taguchi et al.(1998) and

Table 3. Estimated discharge of wastewater

	Sewage flow rate (m^3/day)	Discharge loads(kg/day)	
		BOD	T-P
Original loads	30.1	0.61	0.123
Additional loads	22.0	0.11	0.044
Total	52.1	0.72	0.167

Table 4. The biological parameters used in the ecological model

No.	Symbol	Definition	Unit	Values
1	α1	Maximum growth rate of phytoplankton at 0℃	/day	0.29
2	α2	Respiration rate of phytoplankton at 0℃	/day	0.05
3	α3	Maximum grazing rate of zooplankton at 0℃	/day	0.04
4	α4	Mortality rate of phytoplankton at 0℃	/day	0.0655
5	α5	Natural death rate of zooplankton at 0℃	/day	0.01
6	α6	Mineralization rate of POC at 0℃	/day	0.0306
7	α7	Mineralization rate of DOC at 0℃	/day	0.0245
8	KSP	Half saturation constant for uptake of DIP at 0℃	㎍-at/L	0.25
9	KSN	Half saturation constant for uptake of DIN at 0℃	㎍-at/L	5.00
10	P*	Function of grazing	㎎C/㎥	75
11	μ	Digestion efficiency of zooplankton	%	70
12	ν	Total growth efficiency of zooplankton	%	30
13	λ	Ivlev index for grazing	/(㎎C/㎥)	0.01
14	κ	Percentage of the quantity decomposed from POC to DOC	%	20
15	K1DO	Half concentration of DO for mineralization of POC	㎎/L	1.00
16	K2DO	Half concentration of DO for mineralization of DOC	㎎/L	1.00
17	Ka	Reaeration coefficient at water surface	/day	0.016

Taguchi et al.(2009) and literature of Kim et al.(2002), Kim et al.(2007), Hong et al.(2007), Eom(2007), and Hong et al.(2008) (Table 4).

3.2 Reproducibility of ecological model

Simulation was conducted until 6 of state variables showed the steady states to reproduce the water quality of the reservoir. We confirmed the applicability of the model to the study area by comparing the observed data and the estimated data. To check the reproducibility, DO, COD, Nutrient and Chl.a were simulated because DO is necessary for living things to survive, COD is an indicator of oxygen consumption waste in the aquatic ecosystem, and Nutrient and Chl.a show the primary production of phytoplankton.

The result of the simulation was applied in estimating the relative error between the calculated value and observed value. The observed and simulated COD were the same at 3.47mg/L. The observed DO was 8.87mg/L whereas the simulated DO was 8.88 mg/L. In the case of DIP, the observed and the calculated value were the same at 0.011mg/L. In the case of POC and DOC, the observed values were 1403.00mg/L and 2104.50 and the calculated values were 1402.66mg/L and 2104.40mg/L, respectively. In the case of Chl.a, 12.89mg/m^3 was observed whereas 12.86mg/m3 was the simulated value.

The relative error of Chl.a and DO were 0.23% and -0.11%, respectively, and in the case of POC and DOC, 0.02% and 0.01%, respectively. Therefore, the relative errors of state variable were good enough to be applied.

The reproducibility of the model was satisfactory with the relative error ranging between the calculated value and the observed value (Fig. 3).

3.3 Results of simulation

After applying the additional wastewater discharge from the industrial complex, the water quality on reservoir was estimated. The original load was 30.1

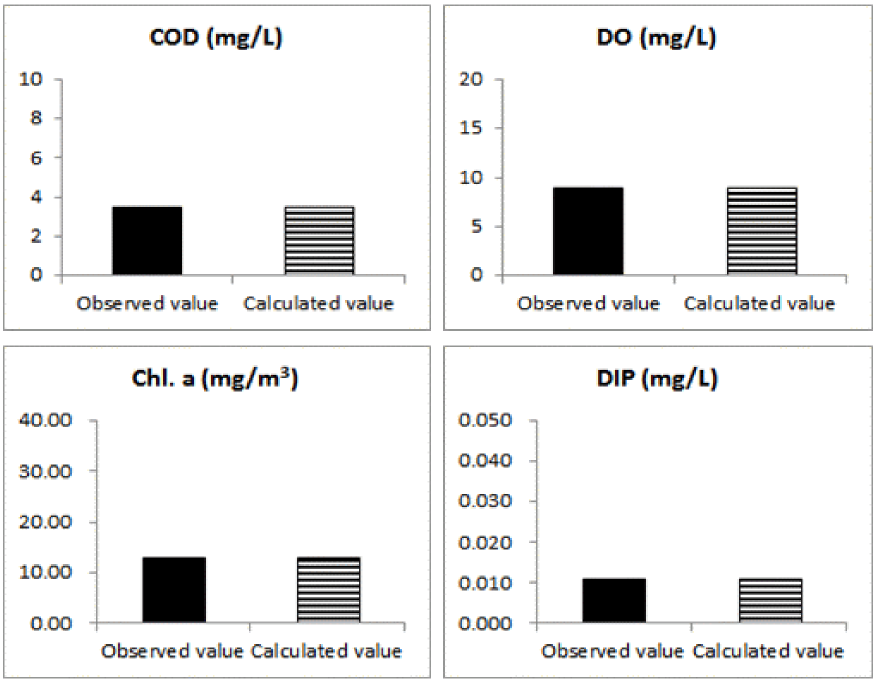

Fig. 3. Comparison of the observed value and the calculated value.

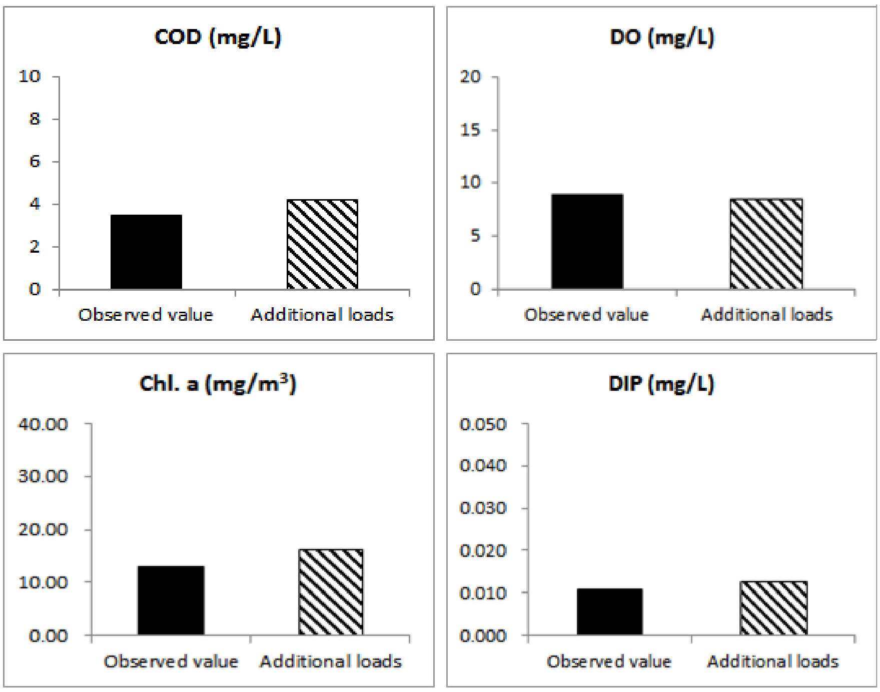

Fig. 4. Comparison of the observed value and the simulated value after applying the additional loads.

m^3/d and the additional load was assumed to be 22.0 m^3/d. The additional load was assumed based on the area of the industrial complex and the estimated population. The discharge loads of BOD and TP were assumed to be 0.11kg/d and 0.04kg/d. These are 15.3% and 26.4% of the total discharge loads in this study area, respectively.

The concentration of COD was increased 20.2% from 3.47mg/L to 4.17mg/L when additional discharge loads were applied, but DO decreased 4.8% from 8.88mg/L to 8.45mg/L. In the case of Chl.a, the concentration increased 26.6% from 12.89mg/m^3 to 16.32mg/m^3. DIP increased 18.2% from 0.011mg/L to 0.013mg/L (Fig. 4).

4. Conclusion

This study was conducted to estimate the water quality and predict the effect of industrial discharge in Koejong-reservoir using the ecological model. Wastewater discharge from the warehouses, plants and houses flows into the study area and construction of a new industrial complex is being planned. The ecological model consisting of POC, DOC, phytoplankton, zooplankton, DIP, DIN, DO and COD was applied to characterize the state variables of the ecosystem and simulate the lake environment.

The observed value of initial conditions for compartment was applied to the model. The original discharge and 6 of state variables were estimated, and the simulation was conducted until 6 of state variables show the steady states. The observed and the simulated COD were the same at 3.47mg/L. The observed DO was 8.87mg/L and the simulated DO was 8.88mg/L. In the case of DIP, the observed and the calculated values were the same at 0.011mg/L. In the case of Chl.a, 12.89mg/m^3 was observed and 12.86mg/m^3 was simulated. The reproducibility was satisfactory with a relative error ranging between the calculated value and the observed value.

The relative error of Chl.a and DO were 0.23% and -0.11%, respectively, and in the case of POC and DOC, 0.02% and 0.01%, respectively. Therefore, the relative errors of state variables were good. The proposed ecological model has good enough reproducibility to be applied to other ecosystems.

After applying the additional industrial discharge on the Koejong-reservoir, the result of the water quality simulation indicated that COD and DO were estimated to be 4.17mg/L and 8.45mg/L, respectively. In the case of Chl.a and DIP, 16.32mg/m^3 and 0.013 mg/L were simulated. The increment percentages of Chl.a, COD and DIP were 26.6%, 20.2% and 18.2%, respectively. In the case of DO, the concentration decreased 4.8%.

Therefore, this study shows the water quality change and effect by the pollution. With this ecological simulation, we can consider about the environmental change easily. Before the building project construction, this would be used to protect our environment and reduce the damage on the ecosystem from the pollution.

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