WATER QUALITY MANAGEMENT IN AN ARTIFICIAL LAKE

Jin-Kwan Kim
Ph.D student, Korea University, Korea
Hung-Soo Kim
Assistant Professor, Sunmoon University, Korea
Yong-Nam Yoon
Professor, Korea University, Korea
Gyu-Sei Yi
Assistant Professor, Sunmoon University, Korea

Abstract

These days the large housing complex and public facilities are being built near the metropolitan in Korea. The artificial lake is constructed in the complex and facilities for citizens wellbeing. However, there are severe water quality problems in the lake and it is difficult to recover the contaminated water. Even though we makes an effort to improve water quality it does not meet our expectations.

This study demonstrates our effort to set a water quality management system in an artificial lake, called a mirror pond, located at a new national museum in Korea. The purpose of a system is to solve the problem of a long term sojourn of water body, and manage inflow of contaminants and sediments in the sense of engineering approach.

We analyze optimal water supply system using a two dimensional

hydraulic model called RMA-2 for preventing a local eutrophication by smoothly mixing of water body and suggest the methodologies for economical treatment of inflow contaminants and removing sediments which produce a long term water quality problem. The forecasting for long term water quality management is performed by using WASP5 model which is provided by EPA in USA.

1. Introduction

Water quality problem has attracted the attention of engineers and scientists for a long time and much progress has been made in understanding water quality management problem. Since 1980 the recovery techniques for lake or pond contamination has developed. These days, the forecasting techniques of many water quality problems in the lake has also developed and applied for water quality management. The previous researches has been performed for the cause and treatment of eutrophication (Rochlich, 1969), nutrition and eutrophication (Likens, 1972), Lake and its recovery (USEPA, 1979), nutrition ecosystem (Barica, 1980), and ecosystem of fresh water and phosphor (Persson, 1988) (referenced in Harper and Brown, 1999).

The previous studies invoked our interest for optimal water quality managemnet of Mirror pond in Korea. This study uses RMA-2 model for the analysis of hydraulic characteristics and we suggest a methodlogy for efficient water quality management after long term water quality forecasting using WASP5 model.

2. Model Description

2.1. RMA-2 model

The model consists of the full nonlinear shallow water equations, depth averaged to two dimensions, together with the continuity equation. Turbulent energy is represented by an eddy viscosity analogy. Forces due to bottom friction, wind stress and Coriolis effects are also included. The model is also capable of representing the influence of a fixed baroclinic distribution. The basic equations based on continuity and kimematic wave are as follows

$$\frac{\partial h}{\partial t} + h\left(\frac{\partial h}{\partial x}\right) + u\left(\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y}\right. = 0 \qquad (1)$$

The approach used is the finite element method, which represents the continuum as a series of discrete elements connected at nodes and develops a solution for the reduced system. Elements consist of curved quadrilaterals, triangles and line elements. An implicit time scheme is used for time dependent systems. Several iterations are required for each solution.

2. 2. WASP5 model

The Water Quality Analysis Simulation Program 5 (WASP5) is an enhancement of the original WASP (Di Toro et al., 1983; Connolly and Winfield, 1984; Ambrose, R.B. et al., 1988). This model helps users interpret and predict water quality responses to natural phenomena and man made pollution for various pollution management decisions. WASP5 is a dynamic compartment modeling program for aquatic systems, including both the water column and the underlying benthos. The time varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program.

The WASP5 system consists of two stand alone computer programs, DYNHYD5 and WASP5, that can be run in conjunction or separately. The hydrodynamics program, DYNHYD5, simulates the movement of water while the water quality program, WASP5, simulates the movement and interaction of pollutants within the water. While DYNHYD5 is delivered with WASP5, other hydrodynamic programs have also been linked with WASP. RIVMOD handles unsteady flow in one-dimensional rivers, while SED3D handles unsteady, three-dimensional flow in lakes and estuaries. The model flow of WASP is shown in Figure 1.

Figure 1. WASP model flow

WASP5 is supplied with two kinetic sub models to simulate two of the major classes of water quality problems: conventional pollution (involving dissolved oxygen, biochemical oxygen demand, nutrients and eutrophication) and toxic pollution (involving organic chemicals, metals, and sediment). The linkage of either sub model with the WASP5 program gives the models EUTRO5 and TOXI5, respectively. In most instances, TOXI5 is used for tracers by specifying no decay.

The basic principle of both the hydrodynamics and water quality program is the conservation of mass. The water volume and water quality constituent masses being studied are tracked and accounted for over time and space using a series of mass balancing equations. The hydrodynamics program also conserves momentum, or energy, throughout time and space. The basic equations of WASP5 and the component equations of EUTRO5 are as follows

Kinematic Equation. (3)

Continuity Equation.

(4)

EUTRO Model (5)

① Phytoplankton

(6)

② Phytoplankton Phosphorus

(7)

③ Organic Phosphorus (8)

(9)

Orthophosphate Phosphorus

(10)

Phytoplankton Nitrogen

(11)

Organic Nitrogen

(12)

NH3-N

(13)

(14)

NO3-N (Nitrate Nitrogen)

(15)

Cabonaceous BOD

(16)

(17)

Dissolved Oxygen

(18)

3. Applications to A Mirror Pond

3. 1. Study area

The artificial lake, called Mirror pond, will be located within the National Central Museum which is building in Yongsan family park, Seoul, Korea. The area of a pond will be 342,414m2 and its hydraulic properties are represented in Table 1.

Table 1. Hydraulic properties of a Mirror pond

Lake Name	Size (m^2)	Depth (m)	Volume (m^2)	HRT (day)	Site
Mirror Lake	8,200	0.3~0.6	4,400	8.8	A main side of the Museum

Note: HRT is sojourn time of water

3. 2. Climate and Hydrologic charateristics

The study area is cold anticyclone and dry in winter, and hot and wet climate in summer. However, the pond is in the center of urban area and it shows a typical heat island climate which is common in urban area. The climate characteristics is represented in Table 2, and the precipiation and evaporation in Mirror pond is in Table 3.

Table 2. Annual climate characteristics

	Average	Maximum	Minimum
Temperature	12.6℃	38.4℃	-17.1℃
Wind velocity	2.4m/s	2.8m/s	1.9m/s
Wind direction	NNE in winter, SW in summer		
Precipitation	annual average: 1429.4mm		
Sunshine	annual average: 49.8%		

Table 3. Precipitation and evaporation in Mirror pond

Month	pan evaporation (mm)	point precipitation (mm)	Lake evaporation (m^2)	Lake precipitation (m^2)
1	40.3	19.9	231	163
2	47.6	33.5	273	275
3	78.7	55.6	452	456
4	123.2	64.6	707	530
5	135.6	119.3	778	978
6	127.2	180.3	730	1,478
7	112.3	371.2	645	3,044
8	123.8	380.4	711	3,119
9	107.8	144.5	619	1,185
10	92.5	56.3	531	462
11	53.2	66.8	305	548
12	40.0	24.4	230	200
total	1082.2	1516.8	6,212	12,438

Source: Referenced from Annual Report of Meteorological Center, 1968~1998.

3. 3. Analysis of hydraulic characteristics using RMA-2

We analyzed the hydraulic characteristics in Mirror pond using RMA-2. First time, the pond was designed that inflow may be drained through a weir system which was going to be built in the center of lower side in Figure 2 and we analyzed the hydraulic characteristics. As a result shown in Figure 2, this case has a problem which water could not be distributed in the pond and we conjecture the water may have serious water quality problem. After serious investigations, we made a decision to set a new drainage system crossing the pond and the water is out through the new drainage system. This new system can distribute the water crossing the pond and the system has many advantages in water quality problems or water management.

After analysis, we know that the new system may have several positive results such as leading the effective water treatment by local water sojourn time control, sedimentation management in the bottom of the pond, prevention of water quality problem, exchange of water body during rainfall, and water discharge management during drought.

Figure 2. Velocity distribution for a weir system (system-1)

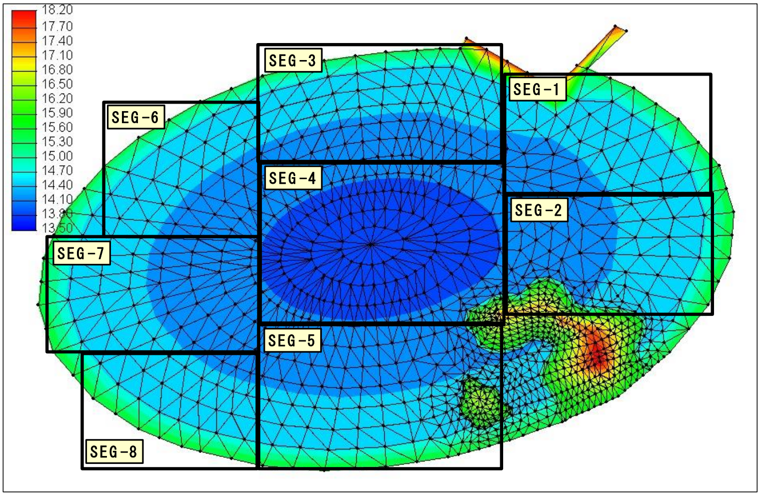
Figure 3. Velocity distribution for a new system (system-2)

3. 4. Analysis of water quality characteristics

(1) Segmentation of the Mirror pond

The segmentaion is the first work for the water quality simulation and it needs some considerations such as boundary of the area, proper mesh, and the estimation of water surface area and water depth. This study divides the pond into eight segments by considering uniform water quality characteristics and the segments can be used for WASP5 (see Figure 4).

Figure 4. Segments for WASP5 model in Mirror Lake



(2) Water quality characteristics of the Mirror pond

The water quality related components are investigated in this section. The quality components in rainfall falling on the pond are shown in table 4. The estimated concentrations of contaminants and pollutional loads in monthly rainfall are also tabulated in Tables 5 and 6. Table 7 shows water and atmospheric temperatures, wind velocity, solar energy, and sunshine rate.

Table 4. Water quality components in rainfall on Mirror pond

(unit : us/cm, mg/L)

		pH	전도도	TSS	COD	TN	TP
Aug. 1996	Begin	-	-	17.5	31.4	-	0.111
	End	-	-	-	9.3	-	0.010
May 1997		5.2	23.8	4.5	5.9	1.25	0.026
July 1997		4.8	14.3	1.9	4.2	0.98	0.067
average		5.0	19.1	8.0	12.7	1.12	0.054

Table 5. Concentration of contaminants in monthly rainfall on Mirror pond

(unit : mg/L)

month	TSS	CODcr	TN	TP
1	4.0	6.4	0.90	0.054
2	3.2	2.5	0.90	0.027
3	5.6	7.6	1.12	0.054
4	7.2	12.7	1.34	0.054
5	8.0	16.5	2.02	0.108
6	13.6	19.1	1.57	0.081
7	7.2	14.0	1.12	0.054
8	7.2	14.0	1.12	0.054
9	1.6	8.9	0.67	0.027
10	21.6	22.9	0.78	0.054
11	12.8	16.5	0.90	0.054
12	4.0	11.4	0.90	0.054
average	8.0	12.7	1.10	0.056

Table 6. Measured pollutional load in monthly rainfall on Mirror pond

(g/day)

month	TSS	CODcr	TN	TP
1	21	34	**4.73**	**0.28**
2	31	25	**8.84**	**0.27**
3	82	112	**16.47**	**0.79**
4	127	224	**23.67**	**0.95**
5	252	521	**63.73**	**3.41**
6	670	941	**77.35**	**3.99**
7	707	1375	**109.98**	**5.30**
8	724	1409	**112.69**	**5.43**
9	63	352	**26.47**	**1.07**
10	322	341	**11.62**	**0.80**
11	234	301	**16.44**	**0.99**
12	26	74	**5.81**	**0.35**
Total (g/year)	99,890	175,024	14,641	725

Table 7. Water and atmospheric temperatures, wind velocity, solar energy intensity, and sunshine rate

month	water temp. (℃)	atmosperic temp. (℃)	wind velocity (㎧)	solar energy intensity (Langleys/day)	sunshine rate (%)
1	1.70	-0.20	1.30	370	0.51
2	3.70	0.60	1.70	470	0.59
3	6.50	1.60	1.90	560	0.58
4	9.90	11.40	1.90	630	0.61
5	14.90	16.70	1.90	715	0.55
6	19.00	20.90	1.70	720	0.47
7	16.10	21.10	1.80	720	0.47
8	19.00	21.40	1.40	755	0.55
9	19.90	20.70	1.20	750	0.60
10	17.00	14.40	1.30	590	0.66
11	11.70	8.30	1.40	490	0.54
12	9.30	2.50	1.30	315	0.51

(3) Target water quality of the Mirror pond

This section describes the target water quality in Mirror pond for human health and each standard for water quality in the pond are shown in tables 8 to 10. This standard will be measured in month and if the standard exceeds the target, we remove several kinds of sediments and fish etc. We decide the plan of water quality management (see Table 11) in Mirror pond based on target water quality components investigated and evaluated.

Table 8. Evaluated standard of nutrient in Mirror pond

	unit	poor	medium	eutrophication
Chlorophyll-a	μg/ℓ	below 7	7~12	above 12
Total Phosphorus	μg/ℓ	below10	10~20	above 20
Secchi Disk Transparency	m	above 3.7	2.0	below 2.0
Primary Productivity	mg-C/m^2/day	50~300	250~1,000	above 1,000
Max. Alage Cell Volume	mm^3/ℓ	1	-	3~5
Total Nitrogen	mg/ℓ	0.25	0.25~1.0	1.0~10.0
Hypolimnetic DO	% saturation	above 80	10~80	below 10

Table 9. Range of eutrophication

	range	remark
Total Organic Carbon	5 ~ 30 mg/ℓ	
Total Phosphrous	30 ~ 5,000 mg/ℓ	
Total Nitrogen	500 ~ 15,000 mg/ℓ	
Fixed Solids	400 ~ 60,000 mg/ℓ	

Table 10. Target of main water quality components

component	Target	target reason
DO [mg/ℓ]	above 5.0	support aerobic state
COD [mg/ℓ]	below 6.0	reduce pollutional load
TN [mg/ℓ]	below 1.0	eutrophication control
TP [mg/ℓ]	below 0.05	eutrophication control
turbidity	below 20	support clean
Chl-a [μg/ℓ]	below 8.0	eutrophication control

Table 11. Water quality management plan

Month	12	1	2	3	4	5	6	7	8	9	10	11
survey components	DO, water temp., PH, turbidity			DO, water temp., PH, SS, TP TN, Chl-a, PO4-P			DO, water temp., PH, SS, TP TN, Chl-a, PO4-P			DO, water temp., PH, SS, TP		
survey number	1/month			3/month			4/month			2/month		
standard for management	turbidity below 20			Chl-a below 8			Chl-a below 8			TP below 0.05		

3. 5. Forecasting water quality using WASP5

If there is no control in the pond DO will be decrease as shown in Figure 5 (square line). In the cases of system-1 (weir system) and -2 (new system) has similar DO preservation (Figure 5) and there is no problems for DO between system-1 and -2 but it may be problem in chlorophyll (Chl-a) especially in June and July (Figure 5). The system-2 shows below 6 for Chl-a which is lower than target Chl-a, 8.

Figure 5. Forecasting DO using WASP5 in Mirror pond

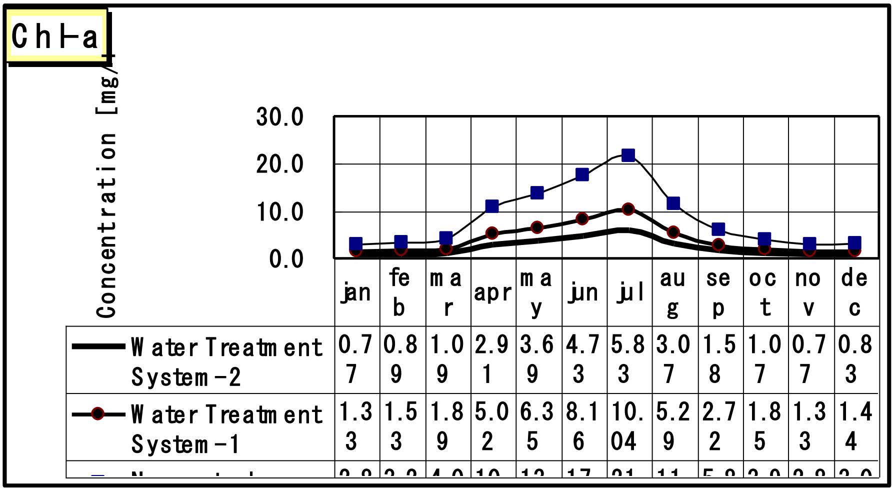
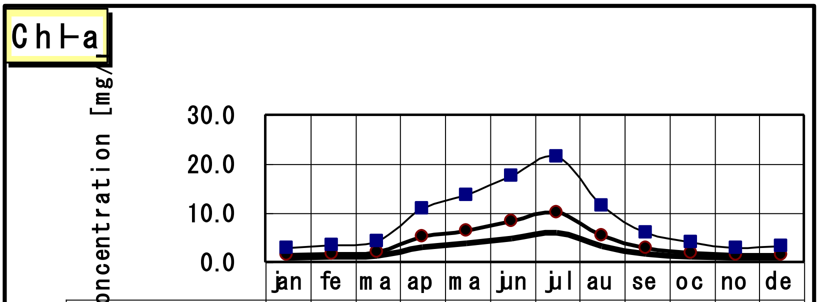


Figure 6. Forecasting Chl-a using WASP5 in Mirror pond



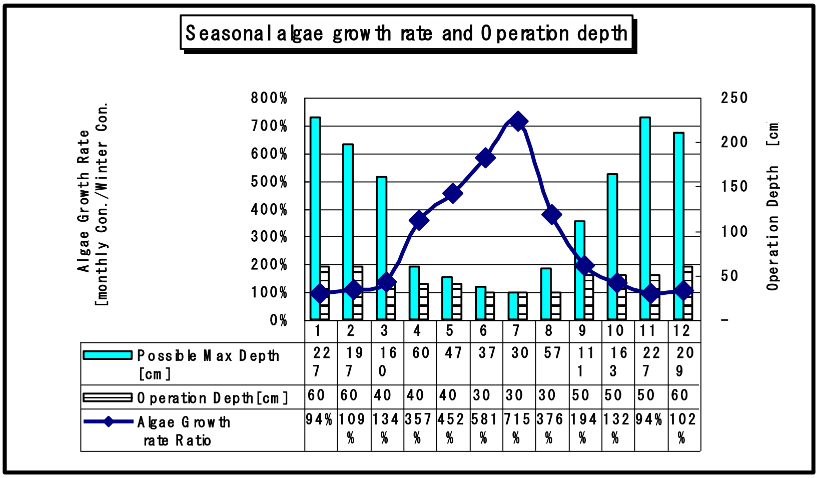
	jan	fe	ma	ap	ma	jun	jul	au	se	oc	no	de
Water Treatment System-2	0.77	0.89	1.09	2.91	3.69	4.73	5.83	3.07	1.58	1.07	0.77	0.83
Water	1.3	1.5	1.8	5.0	6.3	8.1	10.	5.2	2.7	1.8	1.3	1.4

4. Optimal Water Supply Management

The optimal water supply management is related to water depth, volume, and water supply cost. The purposes of optimal water supply management are for cost, safe for children, water quality, and scenery and the results of analysis are shown in Figure 7. Based on considerations such as algae growth rate, water quality, and scenery we decide the operational water depth as shown in Figure 8. The water treatment system is shown in Figure 9 and final optimal water quality management system (system-2).

Figure 7. Cost of water supply in water depth and volume

Figure 8.



	1	2	3	4	5	6	7	8	9	10	11	12
Possible Max Depth [cm]	227	197	160	60	47	37	30	57	111	163	227	209
Operation Depth [cm]	60	60	40	40	40	30	30	30	50	50	50	60
Algae Growth rate Ratio	94%	109%	134%	357%	452%	581%	715%	376%	194%	132%	94%	102%

Figure 9. Water treatment system

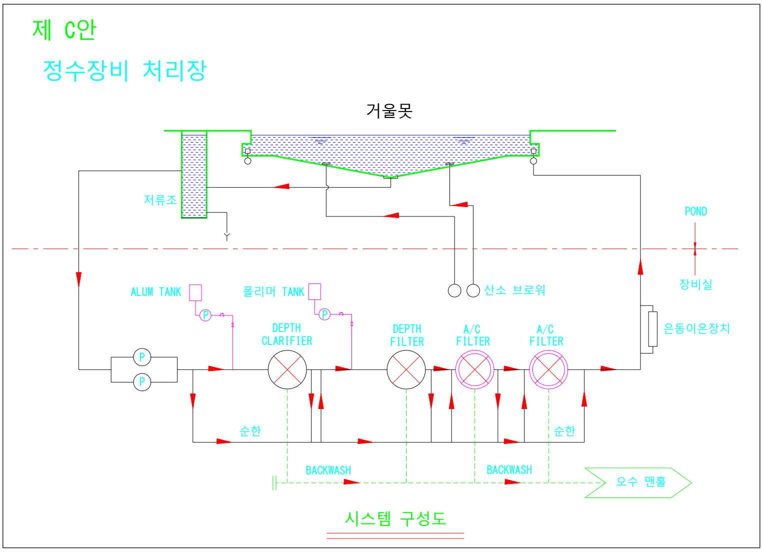
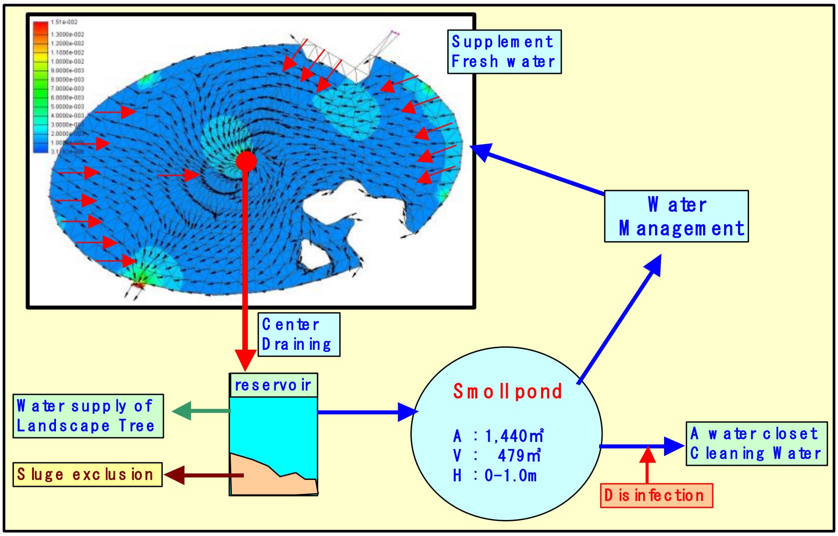


Figure 10. Optimal water quality management system (system-2)



5. Conclusions

We have shown the analysis results of hydraulic charactersitics using RMA-2 and water quality characteristics using WASP5. From the analysis of hydraulic characteristics, we decide the system-2 to solve local water body problem and from water quality characteristics we plan to set eutrophication control and optimal water quality management which maintains below 5mg/㎥ for Chl-a concentration. The new system may have advatages for optimal water quality and water management in the lake or pond.

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