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Analysis of Hydraulic Characteristics on the Water Circulation Efficiency in an Artificial Lake Using MIKE 21 FM

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Abstract

This study analyzed Changes in water level, velocity and water exchange rate of Cheongna Central Lake using MIKE 21 Flexible Mesh (FM) model. The Artificial Lake that changes according to the operation conditions such as the use of flow generator, drainage location and discharge supply condition.

The results revealed that the rate of a lake's water cycle rose when the flow generator operated, causing the water to run at higher velocity in the stagnation regions. Especially, operating the drainage halls located in both ends of the lake showed better water cycle efficiency than using a drainage hall in the center of the lake.

This study suggests management plans to solve dead water regions and enhance the water cycle in the artificial lake. The test result from numerical model in this study will hopefully serve as fundamental data used on designing similar facilities going forward.

Keywords*: Artificial Lake, Hydraulic Characteristics, Water Circulation, Aeration*

1. Introduction

In lakes or reservoirs, the low velocity of running water produces dead water regions, while nutritive substances such as nitrogen and phosphorus cause eutrophication phenomenon. These environmental problems occur quite frequently, particularly in artificial lakes which were built to provide waterfront space in urban areas. An artificial lake, due to its limitation in water supply system, has difficulty performing natural purification, and what is worse the stagnant water flow is increasing the number of dead water regions. There is however an increasing number of efforts to reduce the dead water regions through the adoption of flow generation facilities. These facilities speed up the velocity within water bodies, shorten water's residence time and reduce the efficiency of sedimentation onto lakebed, resulting in the reduction of nutrient accumulation [1]. Therefore, our study continued to figure out the changes of hydraulic characteristics brought by the installation of flow generation facilities, including statistical analysis on the facilities efficiency.

Raymond, Linda, Kenneth, and Kim (1994) analyzed the aerator designs for water quality. They reported that the hypolimnetic aeration using partial lift and full lift aerator designs resulted in enhanced water quality [2].

Lindenschmidt and Hamblin (1996) studied to incorporate a model of the stirring effects of a network of hypolimnetic aerators in the DYRESM water quality model and to present results on its impact on the annual thermal regime of a small urban lake. And they suggested that the design of the hypolimnetic aerators employed in Lake Tegel behave more closely to a bubble plume and there is considerable mixing between the hypolimnion and epilimnion [3].

Choi (1997) evaluated the efficiencies of water quality improvement of the stratified lakes by injecting air into the hypolimnetic zone of the Lake [4].

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Choi, Kim, Yoon and Han (2011) studied the cases of artificial waterways and lakes that have water cycle system. Their study aimed at finding the measures how to sustain the quality of water at required level by experimenting on water quality models when flow generation facilities were installed in these waterways and lakes [1].

As above, many diverse studies and researches have been conducted related with the quality of water and the effects of flow generation devices, but those concerned with hydraulic flow have been scarce. The changes of water level and velocity incurred by the complicated characteristics of water flow within a lake can be unveiled via analysis of numerical model. Considering this, our study used MIKE 21 FM Model and aimed at an artificial lake located in Cheongna area in Incheon, to find out the changes of its water level and velocity with different conditions such as operation and non-operation of flow generator, drainage location and discharge supply condition, and to analyze the lake's water exchange rate.

The Cheongna Artificial Lake consists of central lake, east-west and south-north waterways as can be seen in the Picture 1. The Table 1 shows the data of Cheongna Canal Way.

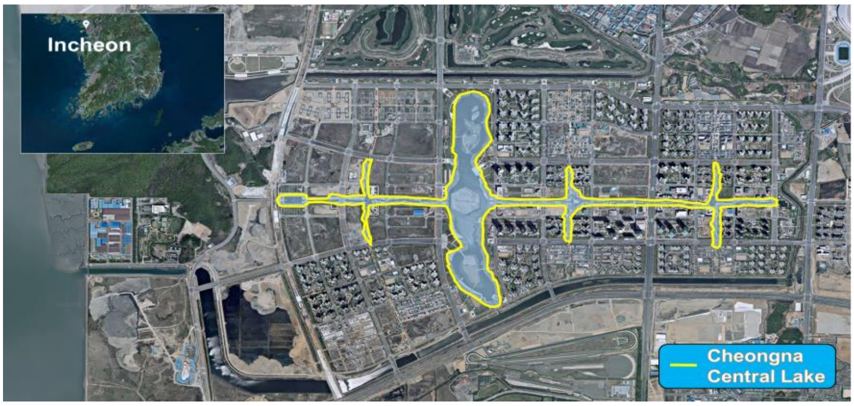


Figure 1. Location of Study Area: Cheongna Central Lake, Incheon, South Korea. Copyright 2016 NAVER [5]

Table 1. Specification of Artificial Lake in Cheongna, Incheon [6], [7]

Water ways	Elevation (m)	Width (m)	Length (km)	Volume (m^3)
Central lake	E.L. -0.5	400.0	2.0	325,392
East-west	E.L. 0.0	9.0～10.0	3.0	61,699
South-north (1～6)	E.L. 0.0	5.0～8.0	1.5	

The central lake, equipped with flow generators containing surface aerators, underwater pond aerators and designed to fit underwater aerators for artificial lake, runs a water cycle system to relieve dead water regions through purification treatment of inlet water and circulating water. The Picture 2 indicates the locations of flow generators and water purification facilities installed in the central lake and waterways.

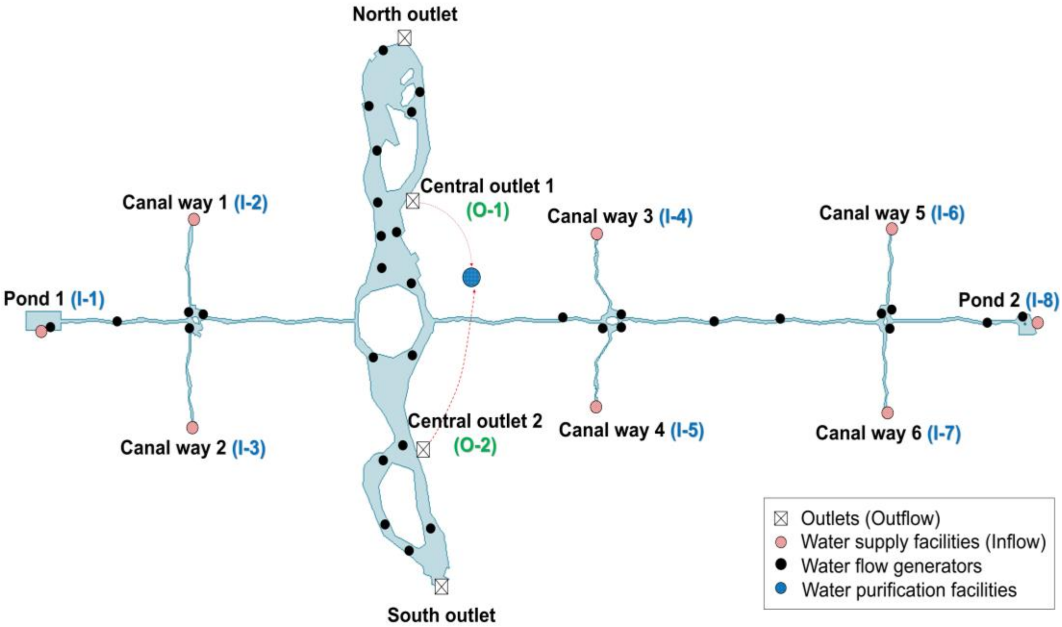


Figure 2. Location of Flow Generators Installed in Cheongna Central Lake

2. Numerical Modeling

This study used MIKE 21 FM to analyze the lake's water exchange rate based on the operation of flow generator. MKE21 version 2007 is use to solve the 2-D vertically integrated shallow water differential equations [8-9]. This model includes the following modules: Hydrodynamic Module (HD), Transport Module (TR), Ecology Module (ECO Lab), Oil Spill Module (ELOS), Sand Transport Module (ST), Mud Transport Module (MT), Particle Tracking Module (PT) [10].

The MIKE 21 FM's Hydrodynamic Module (HD) helped our understanding of characteristics of hydraulic flow and its Transport Module (TR) was used for analyzing the water exchange rate.

2.1. Model Setup

In this study, the function of MIKE Zero Model's mesh generator were used to constitute the geographical data and mesh of Incheon Chengna Central Lake. The MIKE Zero Mesh Generator is a tool for the generation and handling of unstructured meshed, including the definition and editing of boundaries [9].

The altitudes of east-west & south-north waterways were set at E.L 0m, that of central lake at E.L. (-) 0.5m, and a total of 3,330 meshes were set up. And the boundary condition and input data of Hydrodynamic Module and Transport Module are shown in the Table 2.

Table 2. Input Data of Hydrodynamic & Transport Modules

Hydrodynamic module						Transport module	
Duration	Initial condition (m)	Coefficient of roughness	Boundary conditions (m^3/s)			Boundary conditions (mg/L)	
			Inflow #1～8	Outflow		Initial concentration	Inflow #1～8
30 days	1.0	0.028	0.023	1	0.115	0	1
				2	0.069		

2.2. Verification of Numerical Model

2.2.1. Roughness Coefficient

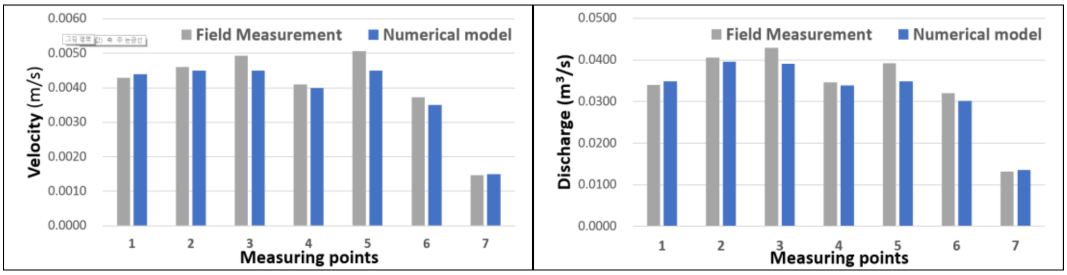
The comparison between the figures measured on the site and those from numerical simulations at different roughness coefficients showed following results.

When the study used Manning's roughness coefficient where n=0.028 for verification, the range of error rates was 2.20～11.15%, and the average error rate was 5.05%, the lowest among the results from individual roughness coefficients. The Table 3 shows the results of the simulation for velocity in each roughness coefficient

Table 3. Results of the Simulation for Velocity in each Roughness Coefficient

Roughness coefficient	Velocity at measuring points							Range of error rate (%) (Max. ~ Min.)	Average error rate (%)
	P-1	P-2	P-3	P-4	P-5	P-6	P-7		
0.025	0.0045	0.0043	0.0045	0.0039	0.0043	0.0033	0.0014	3.66 ~ 14.42	7.73
0.026	0.0044	0.0043	0.0046	0.0039	0.0043	0.0033	0.0016	1.92 ~ 14.29	7.48
0.027	0.0044	0.0047	0.0047	0.0039	0.0044	0.0034	0.0014	2.95 ~ 13.53	5.93
0.028	0.0044	0.0045	0.0045	0.0040	0.0045	0.0035	0.0015	2.20 ~ 11.15	5.05
0.029	0.0044	0.0039	0.0046	0.0039	0.0044	0.0034	0.0014	1.41 ~ 14.37	7.58
0.030	0.0044	0.0042	0.0046	0.0040	0.0044	0.0034	0.0014	1.26 ~ 12.93	6.28
0.031	0.0044	0.0045	0.0046	0.0040	0.0045	0.0034	0.0014	1.14 ~ 11.54	5.36
0.032	0.0043	0.0042	0.0045	0.0040	0.0044	0.0034	0.0014	0.12 ~ 12.66	6.14
0.033	0.0044	0.0042	0.0045	0.0040	0.0044	0.0035	0.0014	0.95 ~ 12.50	5.92

The Figure 3 shows the comparative results of water velocity and discharge between measured on the site and the numerical simulation.



(a) Verification result of water velocity (b) Verification result of water discharge

Figure 3. Comparison of Water Velocity and Discharge between On-site Measurements and Numerical Simulation Results

2.3. Experimental Conditions and Analysis Methods

The changes of water level and velocity were analyzed by applying different water drainage conditions at each time when the flow generator was used or not. The Table 4 below shows the Numerical simulation conditions for MIKE 21 FM. And as shown in Figure 4, the main three section for analysis was selected.

Table 4. Numerical Simulation Conditions

Numerical simulation conditions	Drainage locations	Amount of drainage (m³/day)				Flow generator	Cases
		Central outlet 1	Central outlet 2	North outlet	South outlet		
Designed discharge Supplying condition (16,000 m³/day	Center	10,000	6,000	-	-	Not operated	Case 1
						Operated	Case 2
	South and north	-	-	8,000	8,000	Not operated	Case 3
						Operated	Case 4
	Center, south & north	4,000	4,000	4,000	4,000	Not operated	Case 5
						Operated	Case 6

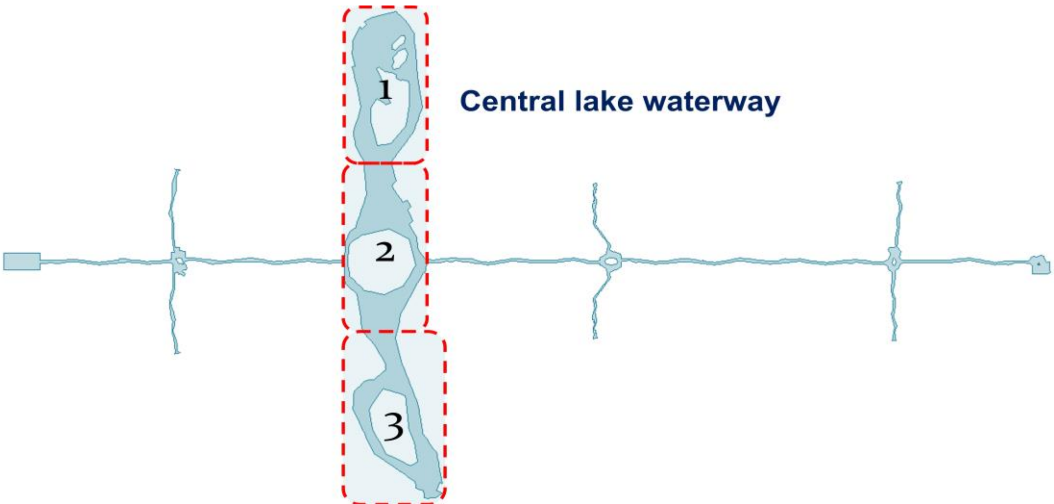


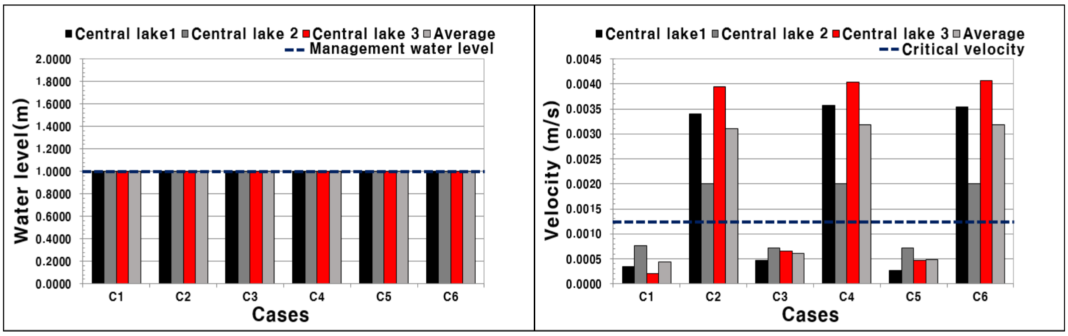
Figure 4. Analysis Sections for Hydraulic Characteristics Results

3. Results of Numerical Simulation

3.1. Change in Water Level and Velocity

From the case 1 to 6, the difference of water levels in different sections was ranged between 0.00 and 0.18 cm, not significantly different from one meter in height which is the water management level.

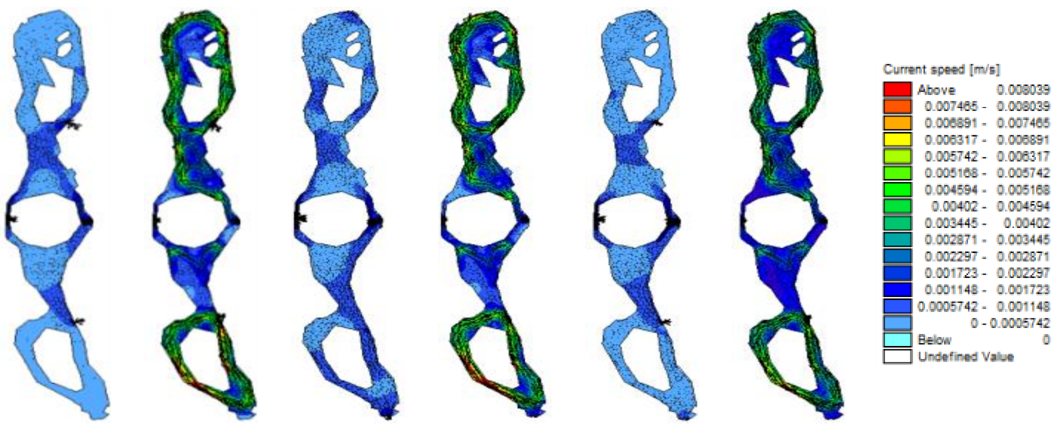
When the flow generator did not operate, dead water regions occurred due to the low water velocity as seen in the cases 1, 3 and 5. On the contrary, the operation of flow generator increased the water velocity by 5.3 to 7.8 times.



(a) Result of water level (b) Result of velocity

Figure 5. Result of Change in Water Level and Velocity under Different Conditions

Figure 6 is the distribution chart of water velocity resulted from numerical simulations based on the MIKE 21 FM.



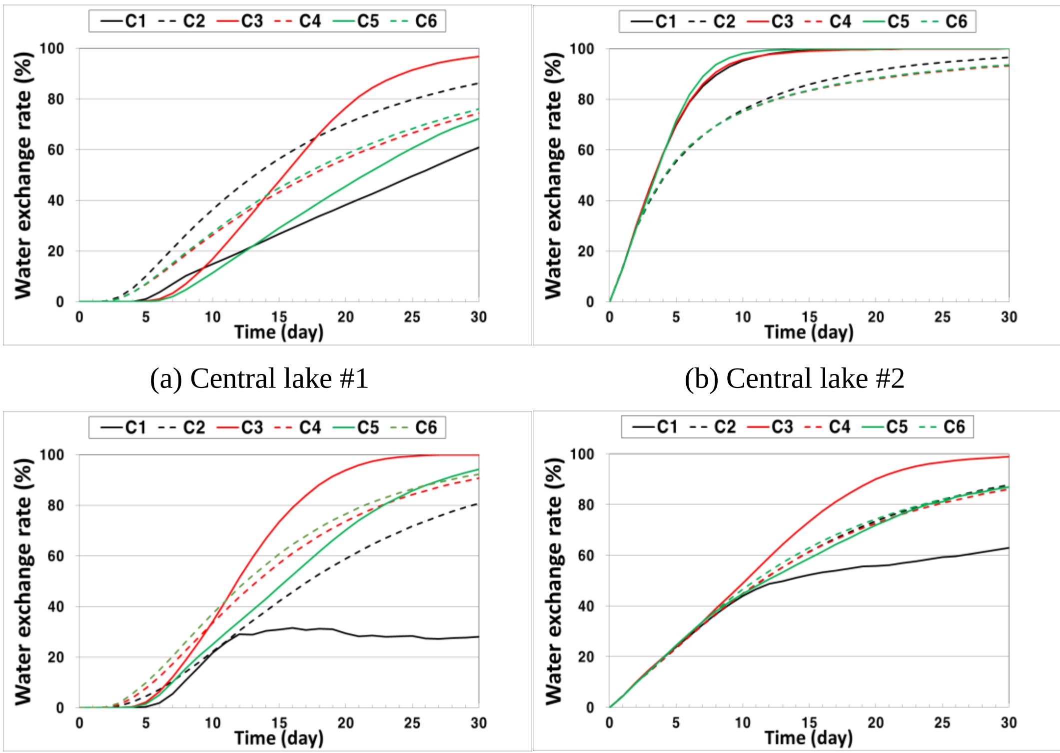
(a) Case 1 (b) Case 2 (c) Case 3 (d) Case 4 (e) Case 5 (f) Case 6

Figure 6. Distribution Chart of Changes in Velocity on Different Experiment Conditions

3.2. Analysis of Water Exchange Rate

From the date when the flow generators stopped operating, the water exchange rate in the central lake #1 started on the fourth or fifth day, whereas it started on the first day in the central lake #2 and on the third or fourth day in the central park #3. When the flow generators started operating, the water exchange rate started on its first day in all sectors, implying that the flow generator substantially influenced the progress of water cycle. The water exchange rate of the entire central park was between 58.4% and 96.1%. The highest rate was shown under the drainage conditions of south and north floodgates when the flow generator did not operate.

Under each drainage condition, when the flow generators operated or did not operate, the water exchange rate increased or decreased, respectively by 37.8% under the design drainage condition, and by (-)17.5% under the drainage condition of south and north outlets, and by 0.6% under equalized drainage condition. The Figure 7 shows the water exchange rate by time under the design condition.



(a) Central lake #1 (b) Central lake #2

(c) Central lake #3 (d) Whole central lake

Figure 7. Results of Water Exchange Rate under the Design Condition

4. Conclusions

This study drew the following conclusion from the numerical simulations using the Mike 21 FM Model to analyze hydraulic characteristics under different conditions such as discharge supply, drainage location, and operation or non-operation of flow generator.

First, the rate of water cycle was higher when the flow generator operated than when it did not operate. The flow generator installed in stagnant regions accelerated the average velocity of running water and increased the rate of water cycle within the lake, which proved that the flow generator is of great use to improve the quality of water.

Second, operating both the south and north outlets (drainage halls) is better in raising the efficiency of water cycle than using the outlets in the center of lake. It is considered that the central outlets will work fine alone in normal times under the set condition, but when the quality of water gets worse, the south and north outlets shall be operated to raise the rate of water cycle and thus improve the quality of water in the lake.

Third, the operation of south and north outlets without operating the flow generator showed the highest water exchange rate. This was because the flow generator actually had forced the water to flow in the opposite direction and interrupted the normal water flow. It is therefore deemed that adjusting the direction of flow generator toward the direction water flow when operating the south and north outlets will enable more efficient management of waterways.

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