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Water quality modeling for the water quality conservation of estuary reservoir in Korea

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ABSTRACT

Hydrologic simulation program-fotran and Environmental fluid dynamics code model were applied for the Hwaseong Reservoir to evaluate water quality improvement by watershed management measures. The models were calibrated against the field measurements of streamflow, BOD_5, COD, T-N, T-P, *Chlorophyll-a* at each observing point (six watershed and nine reservoir observed stations) from 2009 to 2010. The simulated results satisfactorily predicted the seasonal pattern of the observed ones and were within the reasonable range. The four scenarios for water quality improvement were applied to main tributary streams considering previous research reports and the Reservoir entrance from the inflow streams. The results demonstrate that the expansion and upgrade of wastewater treatment plant and pond/wetland construction would be great effective management measures. In order to achieve the target water quality and success the polder project, the measures that can control both point source and nonpoint source pollutants can be a key factor. However, for the stable water quality conservation, it is important to maintain the water quality efficiency rate of the pond/wetland system. Thus, the treatment rate of the water quality by the pond/wetland system should be monitored and maintained consistently.

Keywords: EFDC; HSPF; Pond/wetland construction; Wastewater treatment plant; Water quality conservation; Watershed management measures

1. Introduction

Since the 1970s, Korea has been building estuary freshwater reservoirs by the tidal closing for the secure of both sustainable water resources and reclaimed land. The amount of reservoir water in the estuary after future developments of estuary freshwater reservoir are complete is predicted to be approximately 17×10^9 m^3. This is about 50% of the annual water usage. Thus, such development is expected to greatly contribute to the water resource security. However, the construction of estuary freshwater reservoirs through land reclamation causes the water pollution due to the stagnant reservoir and the isolation from the seas. This blocks the dilution effect by the seawater and causes environmental issues including water quality problems. There are more than 10 estuary freshwater reservoirs distributed along the west coast of the Korean peninsula [1]. These reservoirs all have experienced water quality deterioration and eutrophication phenomena that increased social

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interest on this matter. The wastewater inflow into the reservoirs has increased due to the rapid urbanization and industrialization from upstream watershed. Such makes it hard to manage the water quality. Therefore, there has been much effort on securing not only a certain amount of water resources but also a certain level of water quality.

Hwaseong Reservoir has been going through land reclamation since 1990. The conversion work to paddy field was completed in 2012. There were plans to supply irrigation waters for farmlands in reclaimed land and hinterland. However, due to the delay of the water quality improvement project planned in 2002 and rapid development of the upper stream, the water quality of the Hwaseong Reservoir worsened [2]. This led to the postponement of the desalination time. Currently, the circulation of seawater through the gate is in practice until the reservoir meets its targeted water quality level after completion of the water quality conservation measures. In addition, while there is only a small amount of water inflow from three main tributaries including the Namyang Stream, there are increases in pollution of surface waters by the rapid population growth, indiscriminate industrialization, promotion of livestock industry for the increase of agricultural income, poor disposal of animal excreta, and nonpoint source (NPS) pollutants by urbanization. Thus, the streams are polluted, and such polluted water is flowing into the reservoir. For the desalination and conservation of the reservoir to be achieved, there must be controlled pollutant sources in the upper stream watershed.

In order to evaluate the success of the watershed's water quality management and the practice of water quality conservation measures, long-term monitoring and data collecting are necessary. Also, there must be a pollution assessment and sufficient research of the characteristics of both the watershed and aquatic environment [3]. Based on this, the current and future water quality of the watershed and reservoir can be evaluated and predicted. On the other hand, this can be easily accomplished by verified water quality models. Therefore, according to the model results, a method to effectively control the pollution of reservoir can be suggested [4]. The water quality of the reservoir must be simulated and predicted through water quality modeling in the early stages of planning. If the predicted water quality does not meet the target water quality, appropriate measures must be done for the improvement of water quality. Recently, there have been increased in the applied researches in Korea on water quality models based on watershed like Soil and water assessment tool (SWAT), Hydrologic Simulation Program-Fotran (HSPF), Storm Water Management Model (SWMM), etc. and based on reservoir like Water Quality Analysis Simulation Program (WASP), Environmental fluid dynamics code (EFDC), Generalized Environmental Modeling System for Surfacewaters (GEMSS) to predict the water quality and suggest water quality improvement measures.

This study attempts to predict the water quality according to increase of pollution source and suggest best management measures for the water quality conservation of the Hwaseong Reservoir. To achieve these, its applicability is evaluated in connection with the watershed and reservoir water quality model. HSPF based on BASINS that is applicable to watershed that have a mixture of various land-use characteristics like the rural and urban areas and EFDC that can numerically analyze three dimensions-flows were applied at the same time.

2. Environmental states of Hwaseong Reservoir watershed

The geographic information system (GIS) analysis shows that 60.5% of Hwaseong Reservoir watershed is farmland, 21.5% is the forest, 9.9% is residential area, and 8.2% is others (river, wetland, etc.). This resembles the land use of a typical nonurban area. But the watershed is the region that is coexist with rural and urban area and located on adjacent metropolitan. It is true that the watershed is coming under pressure to develop recently, some areas are densely populated, and other areas undergo sudden changes. The indicated microorganism concentration in the urban area was relatively high. This is because of the highly concentrated population, the discharge of the individual septic tank and sewage disposal plant, and the inflow from unknown sources as the main pollution sources.

All tributary streams in the watershed are small size. But Namyang, Jaan, and Eoeun Stream have great impacts on hydrology of Hwaseong Reservoir at least (Fig. 1). The channel length of these streams is a range of 6.51–13.27 km, and its annual inflow is as low as a range of 0.088–0.265 m^3/s. The storm water runoff goes through various land uses where the pollutants are concentrated. Highly polluted water like domestic sewage, industrial wastewater, and agricultural drainage comes from around the watershed and flows into the stream and reservoir (Fig. 2, Table 1). The portion of NPS pollutants due to rainfall runoff is great because there are industry, livestock, and farmland sporadically distributed across the stream. In other words, the short delivery distance of main tributaries to the entrance of the Hwaseong Reservoir makes it impossible for the water to go through its self-purification

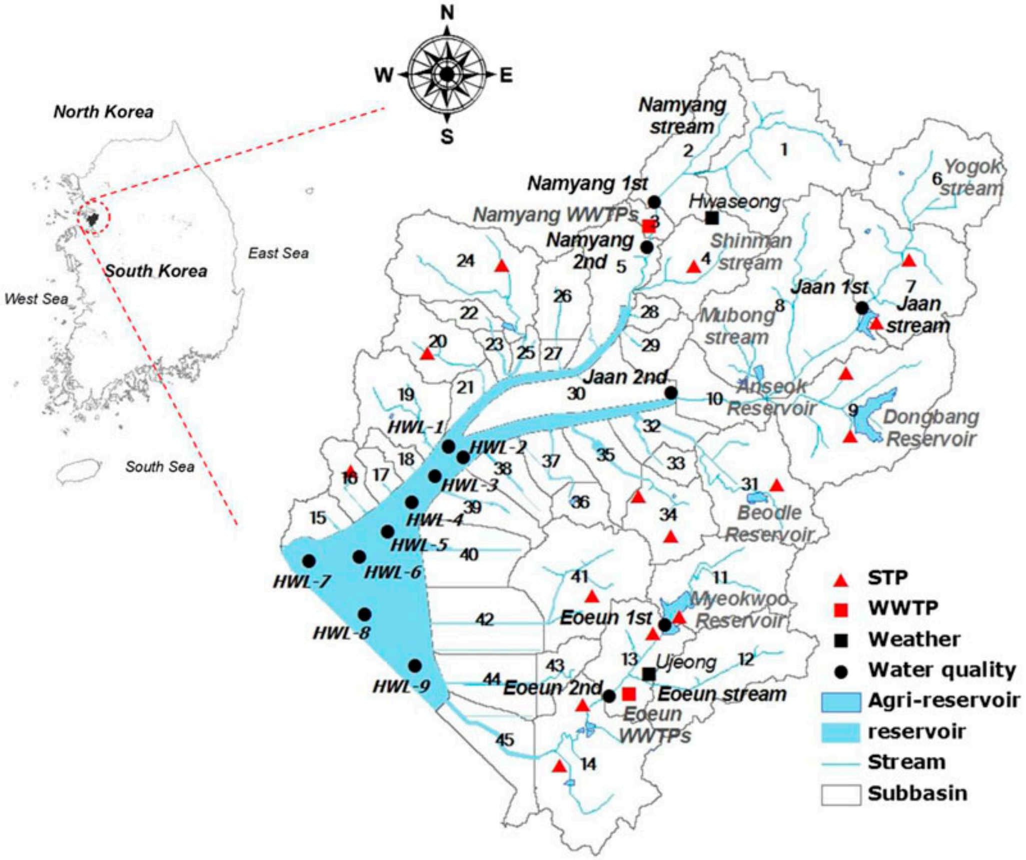


Fig. 1. Site description of Hwaseong Reservoir Basin.

process. Thus, such physical environment and pollution characteristics of the watershed may have negative impacts on water quality of Hwaseong Reservoir.

3. HSPF and EFDC model overviews

HSPF [5] was developed by the United States Environmental Protection Agency (USEPA). This model simulates surface runoff volumes and water qualities for each hydrologic response unit on long-term basis. It is a semi-distributed model with a physical basis and multilayered flow zones from the ground to underground. The domestic and international application of the HSPF for the management of the water quality in the watershed includes analysis of the characteristics of the behavior of the pollutants and suspended sediments [6], estimation of pollutant load [7], improvement of the model to consider the paddy for domestic condition [8], analysis of the reduction effect of pollutants and watershed management, and TMDL management [9], etc.

The EFDC was developed in the Virginia Institute of Marine Science and is continuously managed and developed under the support of USEPA and Tetra Tech. Inc. EFDC is applicable to various water systems including the river, lake, wetlands, estuaries, reservoirs, coastal waters, etc. The simulation of three-dimensional flow, mass transfer/diffusion, and water quality of the water body is possible in a wide range. EFDC is expressed using the finite difference method and the finite volume method for the conservation of mass and volume. The specific of EFDC is described in detail in [10]. The representative international researches include research on the dilution effect due to the inflow of freshwater and shoreline change of the James and York Rivers in Virginia, USA [10], TMDL on the Klamath River located on the border between Oregon and California [11], water quality management of Budd Inlet and South Puget Sound watersheds in Washington, USA [12]. In Korea, the model has been applied to Gyeonggi Bay [13] and researches on analysis of hydraulic and water quality


a. Namyang middle reach
b. Namyang downstream
c. Jaan middle reach
d. Jaan downstream
e. Eoeun middle reach
f. Eoeun downstream

Fig. 2. Site-photos at the main tributaries.

Table 1
The characteristics of main tributaries

Stream	Basin area A_w (km^2)	Stream length L_b (km)	Effective basin width A_w/L_b (km)	Form factor $A_w/L_b{}^2$
Namyang	19.61	8.99	2.18	0.24
Jaan	53.15	13.27	4.01	0.30
Eoeun	23.18	6.51	3.56	0.55

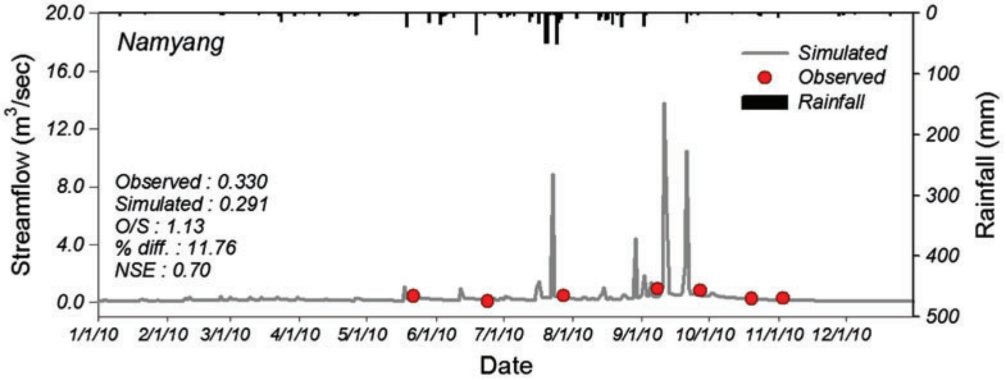
in the Saemangeum Reservoir [14] and Paldang Reservoir [15].

4. Model setup and simulation

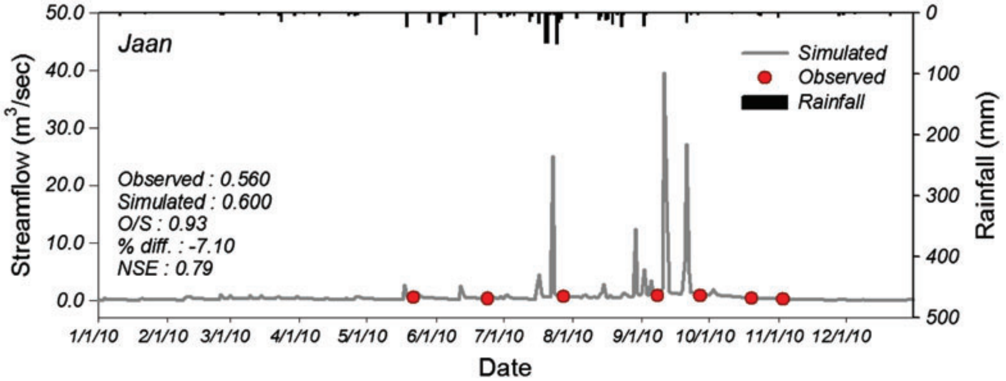
4.1. HSPF model

We used the HSPF model based on the BASINS tool, where the simulator is integrated into a GIS by an Arc View preprocessor. It uses topography, a polygon/grid coverage of soil and land cover, and point coverage of meteorological and pollutant data as basic input to the model. Hydrologic boundary conditions can be derived from watershed boundaries, stream networks, and digital elevation mapping (DEM). Watershed boundaries and stream networks obtained from the National Geographic Information Institute and the DEM data layer from the National Spatial Information Clearinghouse (https://www.nsic.go.kr/

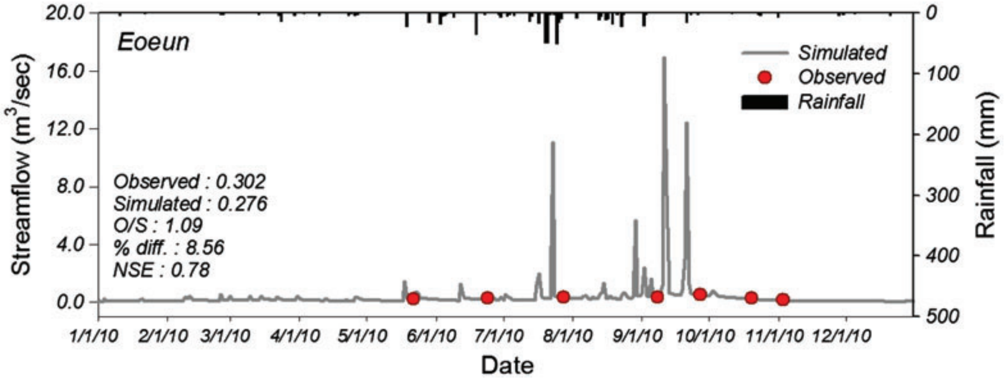
ndsi) were prepared at 30 m × 30 m resolution. Based on the topography of the watershed and burn-in options (digitized streams) using the BASINS tool, the study area was subdivided into 45 smaller, hydrologically connected sub-basins and their stream reaches. Accurate land cover data were essential for correctly estimating impacts of NPS pollution within the District, particularly with its rapid population growth. Land cover data reclassified using raw data (1:25,000 scales in shape-polygon format) from the Environmental Geographic Information System. Metrological data based on hourly time series were used including precipitation, evaporation, air temperature, cloud cover, dewpoint temperature, wind speed, and solar radiation, and relative humidity, cloudiness. When possible, data from the stations such as Hwaseong and Ujeong (Fig. 1) was used to more accurately represent the study area. Point sources (municipal, industrial, livestock, etc.) are significant sources of nutrients and organic material within a watershed. Available point sources discharge records from National Institute of Environmental Research (NIER) consisted of daily val-



a. Namyang stream



b. Jaan stream

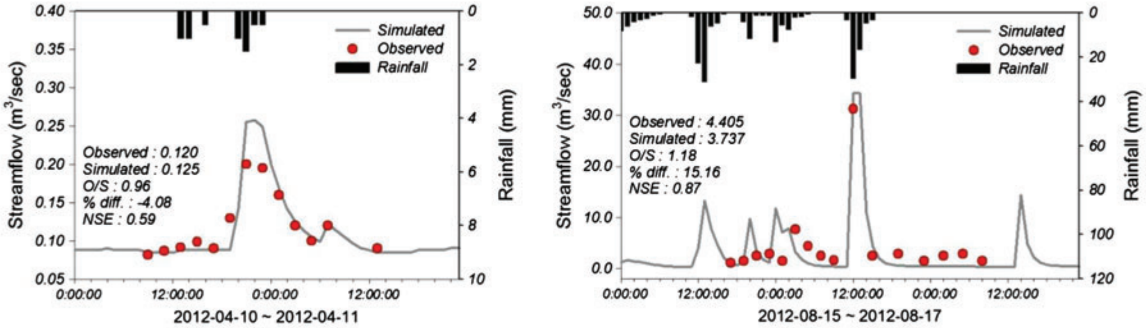


c. Eoeun stream

Fig. 3. Calibration results of streamflow during normal season in 2010.

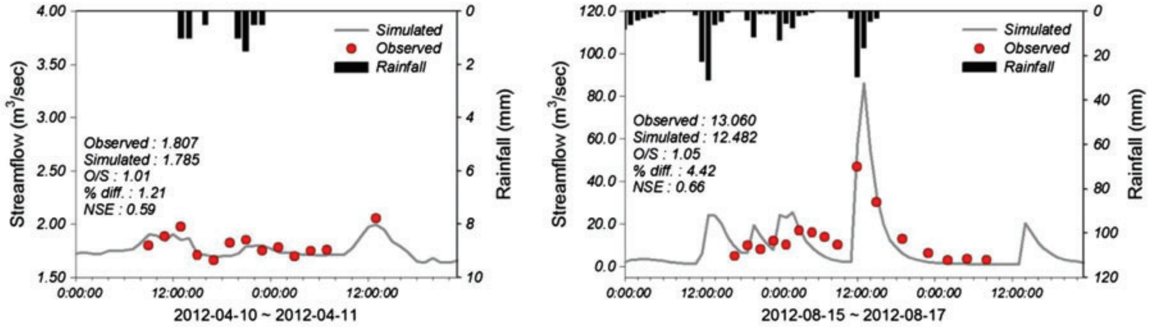
ues for 2010 year at the sub-basin level. In all cases, the input time series should be available at intervals equal to or less than the simulation time step.

To calibrate and verify the HSPF results, observed flow and water quality data were obtained from six gages by operation of Korea Rural Community Corporation and Ministry of Environment (MOE), respectively, in the study area. HSPF results were fitted to the observed daily stream flow, BOD, T-N and T-P from stations of Namyang, Jaan and Eoeun for a two-year period (2009–2010). Year 2010 was used as a calibration period, the remaining year was used for model validation, and further first two years (2007–2008) used for model stabilization. To calibrate model, the parameter values were based on a sensitivity analysis and the characteristics of each sub-basin, and calibration guidelines were derived from the report by [16]. The simulated values were evaluated using quantitative statistics and model efficiency. Quantitative measures of agreement were based on daily observed and simulated mean values; percent difference (% *diff.*; [17]) index and Nash–Sutcliffe model efficiency (*NSE*; [18]). We used the general guidelines for calibration tolerances or targets from HSPF training workshops over the past 10 years [19]. Stream flow was calibrated first, until % *diff.* values for average observed and simulated streamflow were within 15%, and *NSE* was more than 0.7. Water quality was calibrated after the flow calibration and was continued until average observed and simulated values were within 35% % *diff.* and more than 0.5 *NSE*, respectively.



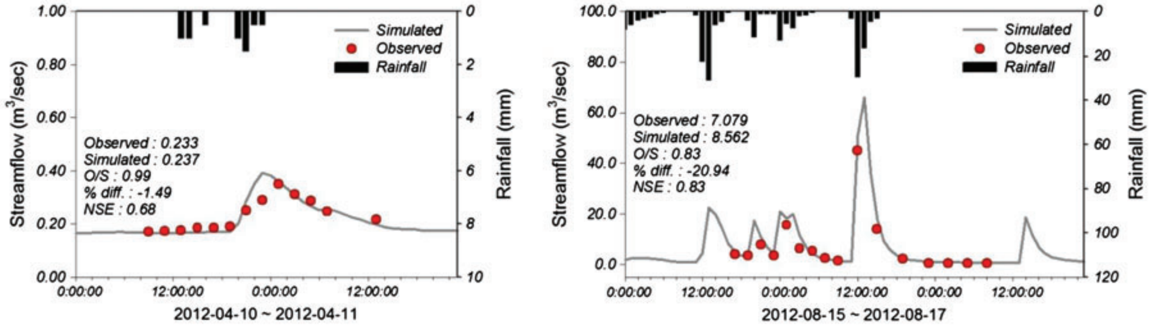
a. Namyang stream (2012-04)

b. Namyang stream (2012-08)



c. Jaan stream (2012-04)

d. Jaan stream (2012-08)



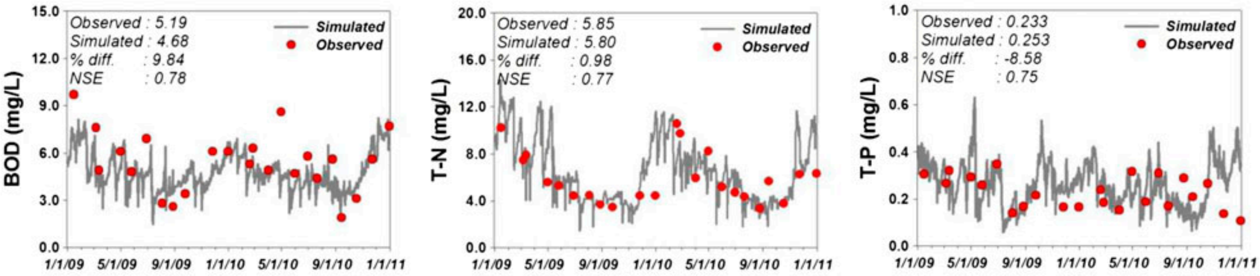
e. Eoeun stream (2012-04)

f. Eoeun stream (2012-08)

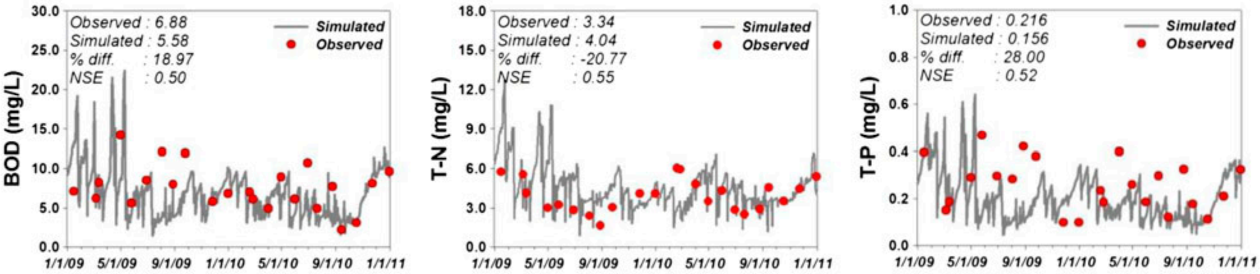
Fig. 4. Validation results of streamflow during high-flow season in 2012.

When it comes to streamflow, the observational data of the target watershed in respect to the simulation period were insufficient, but the calibration for the normal season was completed considering streamflow data in 2010 observed by [2] and based on data of flow regime in main tributaries [20,21]. On the other hand, in order to supplement the peak flow rate of the rainy season, in this study, streamflow data during rainfalls in the spring of 2012 (April 10–11, $n = 13$) and summer (August 15–17, $n = 16$) were measured. Using the observed data during rainfall runoff, hourly flow verification was performed. Parameters like LZSN, INFILT, AGWRC, UZSN, DEEPER, INTFW, etc. that are sensitive to the total streamflow and peak flow rate were mainly modified. The calibration result on daily basis is as Fig. 3. The *% diff.* and *NSE* of all stations each satisfied less than 12%, and more than 0.7, respectively, within the targeted levels. Due to the lack of observed flow data, the calibration of high flows was limited. However, it is considered to adequately describe the observed data during the dry season within the available conditions. The verification result of peak flow rate is as Fig. 4, and this well reflected the flow patterns of each rainfall event on hourly basis. *% diff.* and *NSE* each resulted in −20.94–15.16% and 0.59–0.87, which are satisfactorily within the target range.

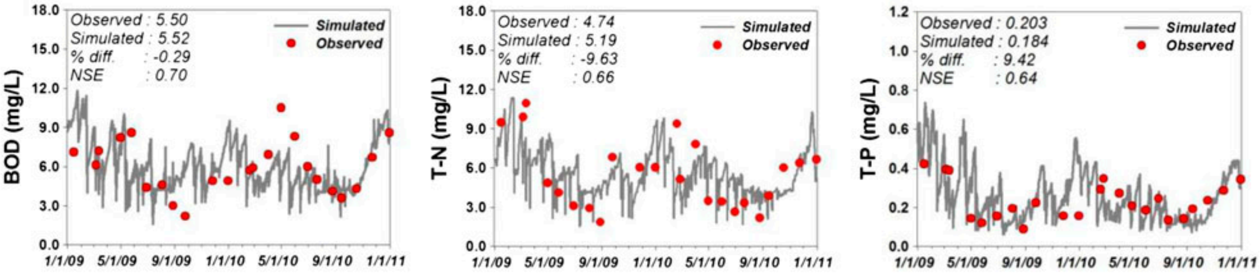
The water quality calibration was based on the monthly observed data of the MOE from 2009 to 2010 and was mainly performed on parameters that are sensitive to each water quality parameter. BOD was modified by KBOD20 and KODSET. Nutrients were modified through the parameters (ACCUM, IFLW, GRND, etc. of the PERLND module) that affect the wash off and accumulation of pollutants. The calibration result of each station is as Fig. 5. BOD was simulated within ±20% of *% diff.* and *NSE* was within the range of 0.70–0.78 except for Jaan Stream. The nutrients were simulated within ±30% of *% diff.* and *NSE* was within 0.64–0.77 except for Jaan Stream. In case of the Jaan Stream, *NSE* was as low as 0.5, but their reliability and performance were within expectations, considering the complexity of the watershed



a. Namyang stream



b. Jaan stream



c. Eoeun stream

Fig. 5. Calibration results of water quality at each second point of the main tributaries.

and pollutant sources. Moreover, the model is reliable for studies on the calculations of the long-term pollution loads and the best management practices using the model.

4.2. EFDC model

The valid grids for the calibration are 428 in the horizontal direction, and five layers in the vertical direction, a total of 2,140. The interval between calculation times (Δt) is 10 seconds. The CPU Time of the 730 days including the 365 days of stabilization period is approximately 12 hours. It was composed of 24 points for input of boundary condition. The boundary conditions of flow and water quality were converted from the watershed modeling results to EFDC input files and the initial condition of the water qualities was input using the data of each water quality observed at the ends of main tributaries. Also, for the downstream boundary condition, the rating curve from the observed gate flow and the water level was used to simulate the present sea circulation state. For the freshwater reservoir condition, the water level is assumed to maintain the managed water level of −1.5 EL.m.

In order to simulate the water quality of EFDC, the calibration of water temperature and DO must be completed preferentially because of its connection with various physical and chemical characteristics of water. It has a direct impact on the water quality of stream and reservoir through its interaction with DO, pH, chemical toxicity, ammonia, and metals, etc. Therefore, this process is needed in the early stages of water quality calibration. On the other hand, the model does not simulated organic matter except for sulfide oxygen demand released from sediment because the source of chemical oxygen demand (COD) in the model is carbonaceous sediment oxygen demand (CSOD) due to sulfide oxidation and nitrogenous sediment oxygen demand (NSOD) due to nitrification. The Hwaseong Reservoir has much pollutant loading with organic matter from the upstream watershed. Therefore, COD must be simulated considering organic matter from watershed in this study. For this, BOD from HSPF model was converted to water quality state variables related to organic carbon and

Table 2
Parameter estimation for EFDC simulation

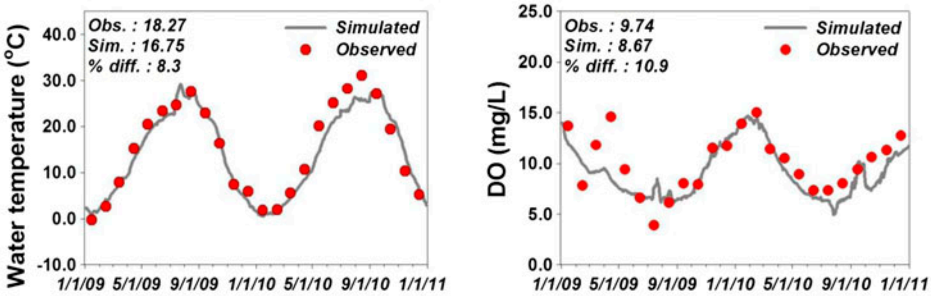
Parameter	Units	Description	Reference (ranges)		[26]	This study
Ke_{TSS}	m^{-1}/gm^{-3}	Light extinction for total suspended solids	[24]	0.0–0.2	0.042	0.042
Ke_{Chl}	m^{-1}/gm^{-3}	Light extinction for total suspended chlorophyll		0.0–0.1	0.017	0.017
CChlx	g C mg^{-1} Chl	Carbon-to-chlorophyll ratio for algae	–	–	$0.06^{(2)}$	0.03
TMx	℃	Optimal temperature for algae growth	[11]	20–25	20.0–27.5	20.0–27.5
PMc	day^{-1}	Max. growth rate for algae	[22]	0.01–4.0	2.5	2.5
BMRx	day^{-1}	Basal metabolism rate for algae	[12]	0.015–0.2	0.15	0.05
PRRc	day^{-1}	Predation rate on algae	[23]	0.101	0.01	0.05
WSx	m day^{-1}	Settling velocity for algae	[12]	0.05–0.5	$0.05(0.01–0.06)^{(3)}$	0.025
WSrp, WSlp	m day^{-1}	Settling velocity for refractory, labile POM		0.05–0.5	0.55	0.05
FPO4	gm^{-2} day^{-1}	Benthic flux rate of phosphate	[24]	0.0006–0.003	0.001	0.00001*/0.002**
FNH4	gm^{-2} day^{-1}	Benthic flux rate of ammonia nitrogen		0.02–0.03	0.009	0.00001*/0.009**
FNO3	gm^{-2} day^{-1}	Benthic flux rate of nitrite+nitrite nitrogen	–	–	0.001	0.00001*/0.001^{**}
FCOD	gm^{-2} day^{-1}	Benthic flux rate of chemical oxygen demand	–	–	0.12	0.12
SOD	gm^{-2} day^{-1}	Sediment oxygen demand rate	[3]	0.06–2.0	−0.64	$-0.378^{*}/-0.64^{**}$

Notes: (1) [26], Establishment of master plan for water quality improvement in Saemangeum Reservoir watershed;
(2) CChlx: 0.01–0.07 within reservoir and the seas;
(3) [27], Application of parameters and coefficients of river water quality model for TMDL plan in Korea.
*Condition of sea water circulation.
**Condition of fresh water (benthic flux rate of phosphate: twice).

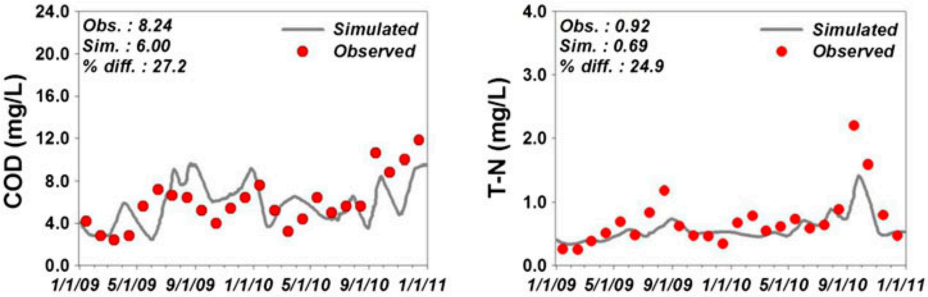
EFDC model was modified to be able to simulate COD considering zooplankton/phytoplankton and organic matter [26]. Water quality calibrations were performed for water temperature, DO, *Chl-a*, COD, T-N, and T-P of HWL-1–HWL-9, using the monthly data observed by [2].

Calibration and validation of water quality was performed in terms of water temperature, DO, Chlorophyll-a (Chl-a), COD, T-N, and T-P from 2009 to 2010 at each observing point. The main parameters used for the water quality calibration is as Table 2. This refers to the applied and measured values of previous studies [3,11,12,22–26]. Especially, in the case of sediment releasing rate, the relatively small release rate value of seawater circulation is caused by the salinocline that limits the release characteristics by internal loading of the reservoir.

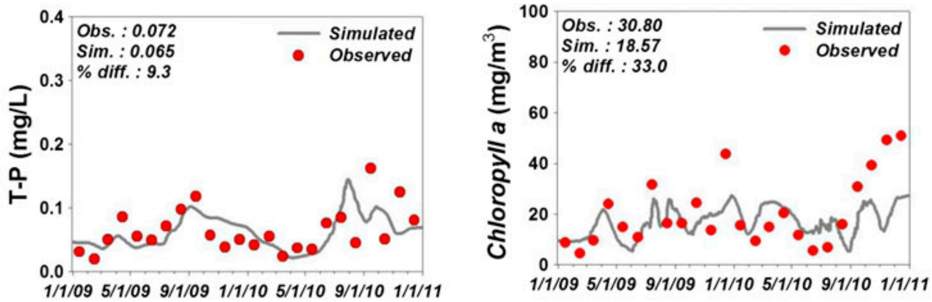
The result of water quality calibration is as Figs. 6 and 7. The % *difference* performed in order to compare the observed and simulated values shows that water temperature and DO are less than 15% and well reflects the trend of observed values. COD, T-N, and T-P were all less than 30%, which was within the target range of model efficiency. Nonetheless, the simulated values were generally less than observed values. In addition, (Chl-a) exceeded 35% at certain stations and was also underestimated than observed values. This is because the decrease of seawater circulation and river improvement works in 2010 had a great impact on the water quality in the reservoir [2]. Also, considering the various water quality characteristics of the reservoir, it can be mentioned that this model generally well reflects the seasonal variation patterns of observed values.



a. Water temperature(°C) b. Dissolved oxygen(mg/L)

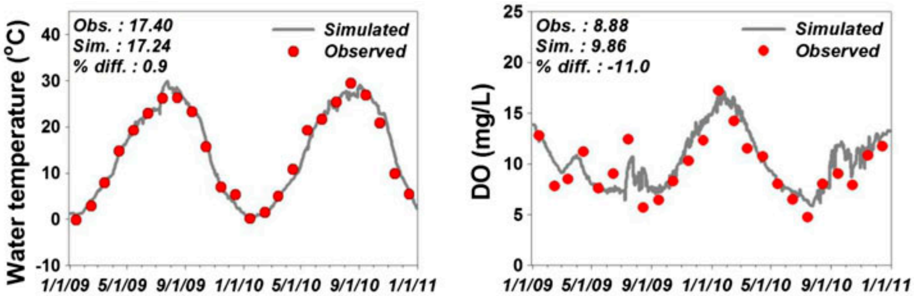


c. Chemical oxygen demand(mg/L) d. Total nitrogen(mg/L)



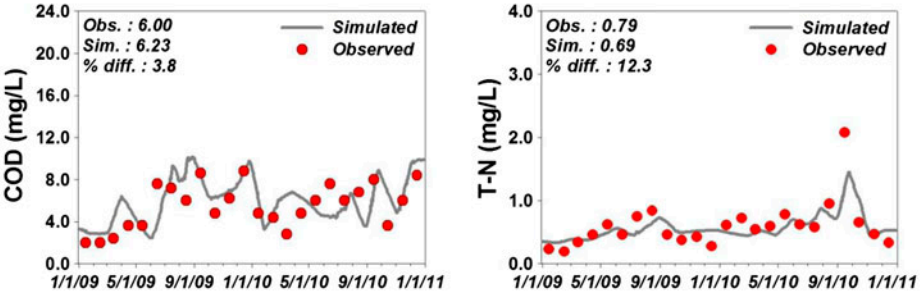
e. Total phosphorus(mg/L) f. Chlorophyll a(mg/m^3)

Fig. 6. Water quality simulation of EFDC at HWL-5 (Center of Reservoir).



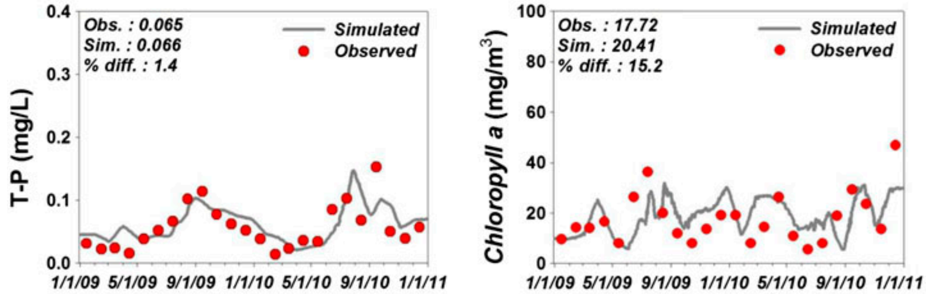
a. Water temperature(°C)

b. Dissolved oxygen(mg/L)



c. Chemical oxygen demand(mg/L)

d. Total nitrogen(mg/L)



e. Total phosphorus(mg/L)

f. Chlorophyll a(mg/m^3)

Fig. 7. Water quality simulation at HWL-7 (Front of gate).

5. Water quality prediction based on the scenarios

Consideration of Hwaseong Reservoir watershed's environment changes is necessary in order to achieve target water quality. Water quality of Hwaseong Reservoir should be within more than Ⅳ grade level as Government policy. Firstly, NPS pollution inflow into the reservoir due to rainfall runoff should be prevented. Furthermore, when streamflow rate is low during the dry season, an intensive water quality management for the highly concentrated pollution water that is discharged from wastewater treatment plant (WWTP) is needed. Hence, a measure to expand an advanced treatment system for the Namyang WWTP was reviewed. One of the advantages of Hwaseong Reservoir's surrounding environment is that the reclaimed land along the shore can be facilitated. Therefore, the plan to manage NPS pollution effectively should be easy to maintain, with highly environmental-friendly purification system like pond and wetland.

The target year to achieve the good water quality was set at 2022 [1]. In this study, pollutant loads in 2022 are estimated, based on the regression analysis on changes in the pollutant sources for 10 consecutive years, from year 2001 to 2010. Four scenarios of Hwaseong Reservoir water quality improvements (Fig. 8) were established.

(1) Scenario 0: No measure taken. This is based on an assumption that the water quality conservation measures implemented from 2002 will be completed by 2012. All the other scenarios are based on scenario 0.
(2) Scenario 1: To reduce the point source pollution of the upstream watersheds, the Namyang WWTP is assumed to be improved as an advanced treatment system. The advanced

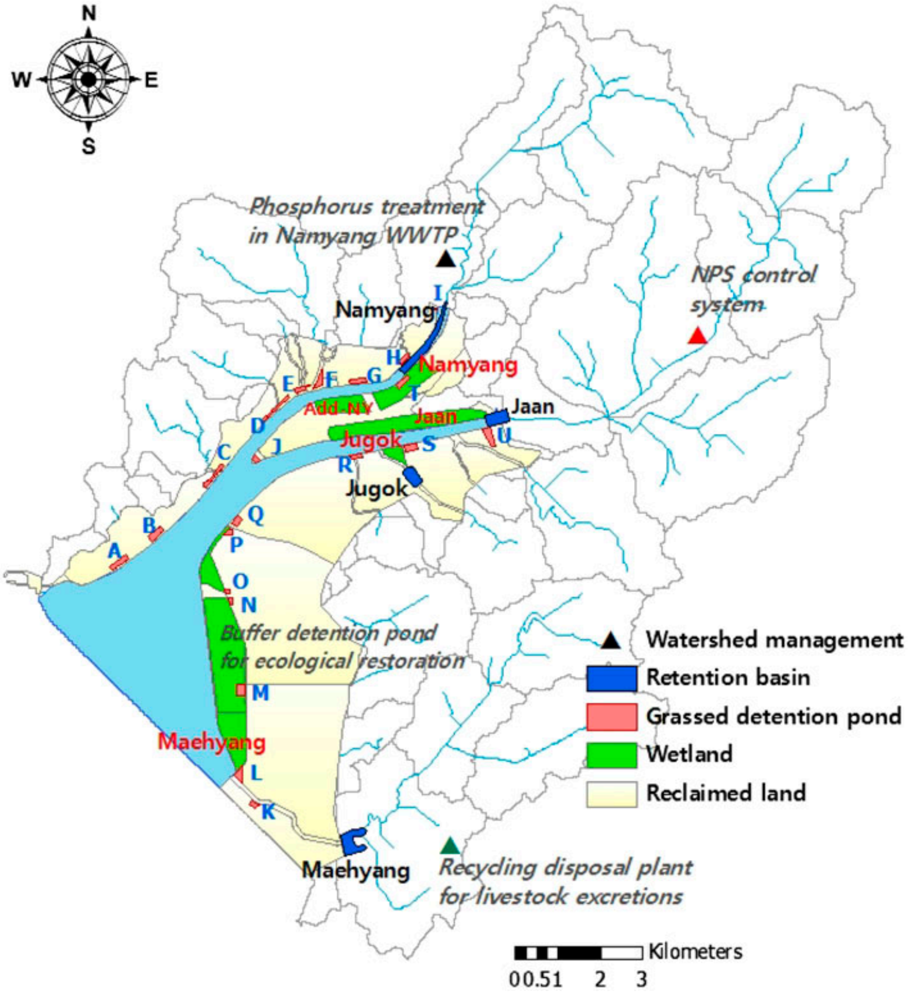


Fig. 8. Site description of measures for water quality improvement.

WWPT was assumed to purify T-P to 0.2 mg/L, according to the act related to sewage discharge concentration in Korea. Considering the present T-P concentration discharged from Namyang WWTP of 0.35 mg/L, the efficiency rate is approximately 43%. The reduction of BOD and T-N was assumed to be 30 and 25%, respectively.

(3) Scenario 2: Besides the wetlands and detention ponds implemented from 2002, the following additional measured were assumed: wetland of 30 ha in the end of the Namyang Stream, Retention basin and wetland of 10 and 40 ha to manage pollution in Jaan Stream, respectively.

(4) Scenario 3: A combination of Scenarios 1 and 2.

Meanwhile, when the wetlands are constructed, the density of outflow based on the characteristics of inflow can be predicted. However, this does not provide enough information to decide the size of the wetland to be constructed. So the first-order treatment wetland models in [28] were applied to roughly calculate the possibility of attaining aimed water quality based on the size of the constructed wetlands and usable area.

$$C_o = C^* + (C_i - C^*) \cdot \exp\left(\frac{-k_T \cdot A}{0.0365 \cdot Q}\right) \tag{1}$$

where C_o = target water quality (mg/L), C_i = water quality of the inflow (mg/L), C^* = background concentration (mg/L), k_T = first order kinetic constant at T ℃ (1/day), A = size of the wetlands (ha), and Q = inflow (m^3/day).

This study applied the value of k_T and the background concentration (C^*) of the wetlands and grassed detention ponds based on the values used in the reviews of water quality conservation measures of the Hwaseong Reservoir in 2003 by the NIER. The researchers also referred to the efficiency rate of diffuse pollution improvement facilities activities in rainfall that the MOE issued in 2008, to calculate the removal rate of pollution (Table 3).

The prediction results of each scenario through the HSPF model are showed in Table 4. Scenario 0 showed on average a concentration of 0.111 mg/L and 8.26 mg/L for each T-P and COD. There were improvement effects in water quality in the overall scenarios where water quality improvement measures were implemented. Especially scenario 2, which includes all possible measures within the reservoir, showed 0.099 mg/L for T-P and 7.93 mg/L for COD. In addition, scenario 3 had the best improvement effects each with 0.097 mg/L and 7.85 mg/L. This implies that the implement of measures for both watershed and reservoir will achieve the target water quality with stability.

Meanwhile, Fig. 9 also presents spatial changes in T-P concentration by seasonal changes (1st quarter: January to March, 2nd quarter: April to June, 3rd quarter: July to September, 4th quarter: October to December) according to the scenarios. In scenario 0, from dry to normal season, there is a diffusion of high concentrated pollutant from the upstream. In the 3rd quarter, where there is a more rainfall, the pollutants are evenly distributed because of the spread and dilution effect of the pollutants caused by rainfall runoff. From scenarios 1 to 3, water quality generally improved as measures were implemented. Scenarios 2 and 3 had almost identical spatial distribution of pollutants, and there were great improvements in spatio-temporal pollution.

Table 3
Parameters for calculation removal efficiency of wetland and detention pond

		BOD	T-N	T-P
k_T (1/day)		93.4	43.1	28.5
C^* (mg/L)		3.5	0.5	0.02
Detention type	Retention basin/ Grassed detention pond	25%	24%	20%
	Wetland	18%	24%	48%

From the above results, the study concludes that the Hwaseong Reservoir watershed needs additional water quality improvement. Considering the water quality improvement effects according to the scenarios and the conditions of the Hwaseong Reservoir watershed, the following measures may be suggested. As of the solutions for water management, the recent social trend to conserve the aquatic environment is to reinforce the water quality standard of effluents from WWTP. It is trend to expand the advanced treatment system in addition to the existing facility. The analysis of the water quality characteristics of the Hwaseong Reservoir watershed shows that the Namyang Stream had a relatively high concentration of nutrients. Due to the expansion of the Namyang WWTP (26,000 m^3), an additional advanced treatment system is in need. Wetland is a representative one of solutions for improving the water quality of reservoir. Wetlands in Korea are generally used to reduce sewage and wastewater. Since it has its goal in high-level reduction, it has a great effect on the removal of nutrients like nitrogen and phosphorous. Not to mention, that it is economically feasible.

Such measure has already been applied in various cases including not only oversea but the Sihwa Reservoir and the Saemangeum basin in Korea. Therefore, when considering further measures for the water quality improvement of the Hwaseong Reservoir, the construction of wetland and grassed detention pond that can be contributed greatly in diffuse pollution control must be considered. Moreover, the function of the wetland is not only attributed to any one factor but a combination of various factors. Therefore, for the sustainability of the water quality purification function

Table 4
Simulation result of water quality behavior by scenarios

	S0 (No BMP)				S1 (Phosphorus treatment plant)			
	Chl-a	T-P	T-N	COD	Chl-a	T-P	T-N	COD
Range	26.55–47.61	0.101–0.121	2.28–2.40	7.75–8.91	26.18–46.64	0.098–0.118	2.24–2.36	7.63–8.75
Average		0.111	2.33	8.26		0.108	2.30	8.12
	S2 (Pond and wetland)				**S3 ((1)+(2))**			
	Chl-a	T-P	T-N	COD	Chl-a	T-P	T-N	COD
Range	25.75–45.77	0.088–0.109	1.71–1.77	7.45–8.53	25.47–44.92	0.086–0.108	1.64–1.71	7.39–8.43
Average	34.30	0.099	1.74	7.93	33.84	0.097	1.67	7.85
Target		0.1	1.0	8.0		0.1	1.0	8.0

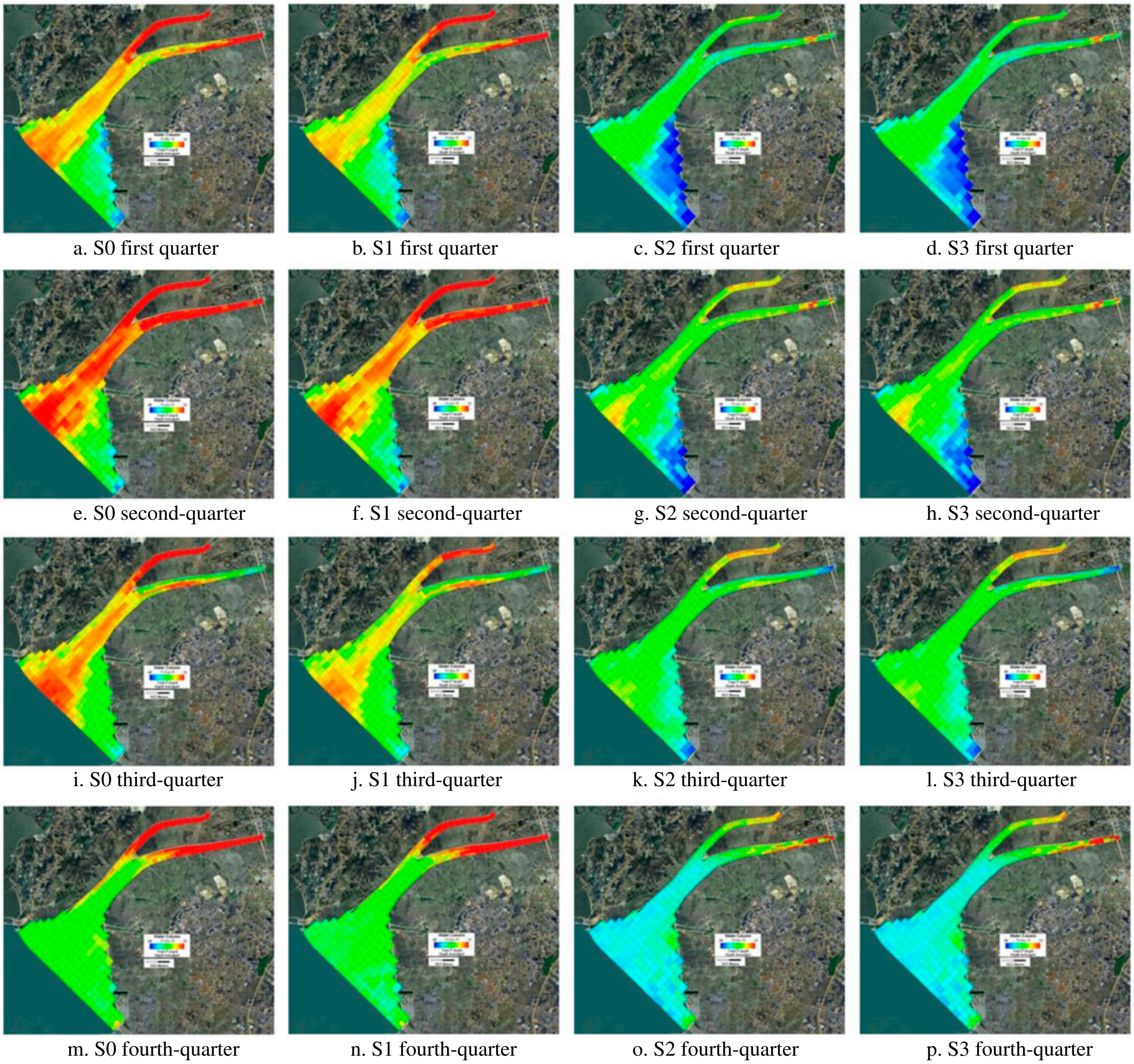

a. S0 first quarter
b. S1 first quarter
c. S2 first quarter
d. S3 first quarter
e. S0 second-quarter
f. S1 second-quarter
g. S2 second-quarter
h. S3 second-quarter
i. S0 third-quarter
j. S1 third-quarter
k. S2 third-quarter
l. S3 third-quarter
m. S0 fourth-quarter
n. S1 fourth-quarter
o. S2 fourth-quarter
p. S3 fourth-quarter

Fig. 9. Time-spatial simulation result of T-P for each scenarios.

and success of the conservation of the reservoir's water quality, various methods including the control of water level, flow improvement, reduction of algal bloom, disposal of wetland plant wastes, management of fishes that cause turbid water, improvement of sedimentation rate of retention basin, etc should be examined and devised.

6. Conclusions

In this study, an attempt was made to evaluate its applicability of the HSPF and EFDC models to improve the water quality of the Hwaseong Reservoir according to the watershed management practice. The results can be summarized as the following.

The HSPF model was set up by inputting the DEM, stream networks, land-use map using the BASINS tool and divided into 45 small sub-basins considering the water quality observatories, reclaimed area, and the reservoir boundaries. First, streamflows were properly calibrated and validated using meteorological data and observed flow rates collected earlier. The simulation results of BOD, T-N, and T-P also properly matched up with the observed values. In order to create internal grids, it was reflected the development plans of the Hwaseong Reservoir and then completed the EFDC model through inputting boundary conditions based on the results of HPSF model.

The improvement effects of water quality in the Hwaseong Reservoir according to each scenario using HSPF-EFDC coupled model, showed that planning more wetlands and grassed detention ponds will greatly improve the water quality. However, for the constant improvement of the water quality purification function and success of the conservation of the reservoir's water quality, various methods should be devised. Because water quality of Hwaseong Reservoir should be within more than IV grade level, if watershed management like the expansion of the advanced treatment system in the Namyang WWTP and lakeshore treatment measures like wetlands and ponds do practices at the same time, the target water quality of the reservoir can be satisfied and remained stable.

From now on, it can be expected to obtain economic benefits coming from the desalination and regional development through application of these measures. In addition, the right time to invest to the improvement plans and the continuous monitoring on the change of pollution sources and land use according to development are needed. Not to mention, well-timed management of governments, intensive regulatory activities, and positive participation of resident. Lastly, in future, it is necessary to be under control the above-mentioned management or operation in response to various demands of water use in the Hwaseong Reservoir.

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References

[1] Gyeonggi-do, Establishment of Measures for Water Quality Conservation of the Hwaseong Reservoir, 2002 (in Korean).

[2] KRC, Tideland Reclamation Project in the Hwaong Reservoir 'Surveyor's Report for Water Quality Management of Estuarine Reservoir', 2010 (in Korean).

[3] S.C. Chapra, Surface Water-quality Modeling, McGraw-hill, New York, NY, 1997.

[4] K.S. Korfmacher, Water quality modelling for environmental management: lessons from the policy sciences, Policy Sci. 31 (1998) 35–54.

[5] B.R. Bicknell, J.C. Imhoff Jr., J.L. Kittle, T.H. Jobes, A.S. Donigian Jr., Hydrological Simulation Program-FORTRAN (HSPF): User's Manual for Version 12, U.S. Environmental Protection Agency, National Exposure Research Laboratory, Athenes, 2001.

[6] B.D. Mitsova, X. Wang, Exploring the variability in pollutant concentrations using BASINS-HSPF and probabilistic modeling: Implications for land use planning, Environ. Inf. Arch. 4 (2006) 186–208.

[7] S. Hayashi, S. Murakami, M. Watanabe, X. Bao-Hua, HSPF simulation of runoff and sediment loads in the Upper Changjiang River Basin, China, Environ. Eng. 130 (2004) 801–815.

[8] J.H. Jeon, C.G. Yoon, K.W. Jung, J.H. Jang, HSPF-Paddy simulation of water flow and quality for the saemangeum watershed in Korea, Water Sci. Technol. 56 (2007) 123–130.

[9] H.S. Hwang, C.G. Yoon, J.T. Kim, Application load duration curve for evaluation of impaired watershed at TMDL unit watershed in Korea, Korean Soc. Water Environ. 26 (2010) 903–909, (in Korean).

[10] J.M. Hamrick, Preliminary Analysis of Mixing and Dilution of Discharges into the York River, A Report to the Amoco Oil Co., The College of William and Mary, Virginia Institute of Marine Science, 1992.

[11] Tetra Tech., Klamath River Model for TMDL Development, Tetra Tech, Inc., Fairfax, VA, 2010.

[12] WDOE (State of Washington Department of Environment), Comprehensive Circulation and Water Quality Study at Budd Inlet, Southern Pudget Sound Water Quality Assessment Study, Prepared by URS Corporation for the Washington State Department of Ecology, 1984.

[13] C.Y. Lee, K.H. Kim, Development of GIS based Water Quality Simulation System for Han River and Kyeonggi Bay Area, Korea Spatial Inf. Syst. Soc. 10 (2008) 77–88, (in Korean).

[14] S.W. Suh, H.Y. Lee, S.C. Yoo, Simulation of water quality changes in the Saemangeum Reservoir induced by dike completion, Korean Soc. Coastal Ocean Eng. 22 (2010) 258–271, (in Korean).

[15] K.W. Jung, Development of 3D Integratted Water Quality Simulation System by Applying BASINS/WinHSPF and EFDC in Han River Basin and Paldang Reservoir, PhD Dissertation, Konkuk University, 2007.

[16] USEPA, HSPFParm, An Interactive Database of HSPF Model Parameters, Version 1.0. EPA-823-R99-004, U.S. Environmental Protection Agency, Office of Water, Washington, DC. Available from the BASINS web site: http://www.epa.gov/ost/basins/support.htm. Accessed 1 May 2013, 1999.

[17] ASCE, ASCE Task Committee on Definition of Criteria for Evaluation of Watershed Models, Irrig. Drain. Eng. 119 (1993), 429–442.

[18] J.E. Nash, J.V. Sutcliffe, Riverflow forecasting through conceptual model, Hydrology 10 (1970) 282–290.

[19] A.S. Donigian Jr. H.S.P.F.Training Workshop Handbook CD. Lecture #19, Calibration and Verification Issues, Slide #L19-22, EPA Headquarters, Washington Information Center, 10–14 January, 2000, Presented and prepared for US EPA, Office of Water, Office of Science and Technology, Washington, DC, 2000.

[20] Gyeonggi-do, Basic Plan for River Maintenance of 5 Streams including of Namyang Stream (Namyang

Stream, Shinnam Stream, Bangrim Stream, Eoeun Stream, Gal Stream), 2009a, (in Korean).

[21] Gyeonggi-do, Basic Plan for River Maintenance of Jaan Stream watershed (Jaan stream, Yogock stream, Mubong stream), 2009b, (in Korean).

[22] R.B. Ambrose, T.A. Woo, J.L. Martin, The Water Quality Analysis and Simulation Program WASP5: Part A, Model Documentation, version 5.1., US EPA Athens Environmental Research Laboratory, 1993.

[23] C.D. Boatman, E.M. Buchak, Application of an ecosystem/water quality model as a tool for managing estuarine water quality, in: Proceedings Fifth Symposium on Coastal Ocean Management, vol. 3, ASCE, Seattle, WA, 1987, pp. 3932–3945.

[24] R.V. Thomann, J.A. Mueller, Principles of Surface Water Quality Modeling and Control. Harper & Row Publishers, New York, NY, 1987.

[25] Y.C. Cho, S.W. Chung, Sediment release rate of nutrients from Namyang Reservoir, Korean Soc. Environ. Eng. 29 (2007) 1345–1352, (in Korean).

[26] NIER, Establishment of Master Plan for Water Quality Improvement in Saemangeum, 2011, (in Korean).

[27] NIER, Application of Parameters and Coefficients of River Water Quality Model for TMDL plan in Korea, NIER NO. 2008-29-979, 2008, (in Korean).

[28] R.H. Kadlec, R.L. Knight, Treatment Wetlands, CRC Press, Boca Raton, FL, 1996, pp. 893–894.