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Effect Analysis Regarding Different Scenarios to Improve Water Quality of the Lake Paldang Basin in Korea

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Abstract

The object of this research is to analyze the water quality improvement of Lake Paldang by implementing Integrated Lake Basin Management (ILBM). To establish ILBM, the basin environment database was built as well as water environment management support system for monitoring present conditions, and predicting changes in basin environment. The major contaminants in Lake Paldang Basin are from domestic pollution, agricultural land, and livestock. Scenarios for reducing contaminants were targeting the increase percentage of sewered population, agricultural and livestock contaminants reduction to analyze the water quality improvement effects. This study applied the SWAT model to Lake Paldang Basin using the basin environment database to improve the water quality of Lake Paldang in Korea. The results of calibration and validation of flow rate, Suspended Solids (SS), Total Nitrogen (TN) and Total Phosphorus (TP) showed that the measurement values and simulation values turned out to be similar, and that it is possible to apply the SWAT model to Lake Paldang Basin. The reduction efficiency of SS by scenario was 11-45%, TN 8-37%, and TP 7-35% and this shows that water quality was significantly improved prior to application. Therefore, to improve the water quality of Lake Paldang, it is recommended to implement the ILBM which is considered to play an important role in making water quality management policy in Korea.

Keywords: *integrated lake basin management, basin environment database, lake paldang basin, GIS, SWAT model*

1. Introduction

Lakes are major water resources that supply water for living and industrial use in human societies, and artificial and natural lakes are used as motive powers that generate energy by hydroelectric power generation. Lakes provide resources for human societies and perform a significant role in sustaining biodiversity. Moreover, lakeshores plants purify water quality, and lakes also play an important role in controlling floods and modulating climate (International Lake Environment Committee: ILEC, 2007). Even though lakes perform such significant roles in human societies, most lake environments worldwide are recently becoming degraded. Many environmental researchers are attempting to improve lake environments, but they face great difficulties in managing lake environments because lakes are extremely vulnerable to external stress (ILEC, 2005). Lakes have the three key characteristics: (1) Long Retention Time, (2) Complex Response Dynamics, and (3) Integration of Nature, which are together defined as the “Lentic Water System” of lakes (ILEC, 2005). Among the issues occurring in lake environments, the issue of eutrophication is closely related to the stakeholders who live in the vicinity of lakes. Eutrophication refers to an increase in the concentration of nutritive salts in the lake due to the inflow of pollutions and release from the lake sediment. As a result, an excessive and rapid growth in plankton population results dissolved oxygen depletion in the lake that leads to perishing of large numbers of fish or foul odors. Nitrogen and phosphorous, which are the causes of eutrophication, flow into the lake due to various pollutant sources such as point pollution sources in the basin and non-point pollution sources produced from agricultural areas, forests and impervious cover. Therefore, to implement reduction measures for various pollution sources, it is necessary to consider the stakeholders within the basin (ILEC, 2005).

Lakes have natural-scientific characteristics and require management by the human society around them such as the involvement of associated stakeholders in the basin. To cope with such characteristics, it is important to take a scientific approach that can explain complicated phenomena with a long-term view. Integrated Lake Basin Management (ILBM) is a scientific approach that has recently been gaining attention as it considers both the basin and human society that affect the lake. ILBM is based on Integrated Water Resource Management

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(IWRM) that is gaining worldwide recognition as a field of water resource management (GWP-TAC, 2000). ILBM can deal with the ecosystem services and lentic water systems that are the distinctive features of a lake (MA, 2005), and it has been proposed by the Global Environment Facility's Lake Basin Management Initiative Project (ILEC, 2007). ILBM is a conceptual framework for assisting Lake Basin managers and stakeholders in achieving sustainable management of lakes and their basins. It takes into account the biophysical features and managerial requirements of Lake Basin systems, that are associated with the lentic (standing or static) water properties of lakes as well as the inherent dynamics between humans and nature in the process of development, use and conservation of lake and basin resources. ILBM assists Lake Basin managers and stakeholders to accomplish better and sustainable management of lakes and their basins. Since lakes are natural assets that provide valuable resources to human and other organisms, they required special management considerations for their lentic (static) water properties. Good lake basin management of a lake can only be accomplished by adopting ILBM, or continuous improvement of Lake Basin governance that integrates institution, policy, participation, science, technology, and funding. Improvement of the state of world's lakes can be achieved by promoting ILBM globally, with long-term and strong political commitment.

Researches on Korean basin models have been conducted to improve water quality of streams and reservoirs in sub-basins (Park *et al.*, 2014; Hwang *et al.*, 2014; Kang *et al*., 2015; Lee *et al.*, 2017), but it is necessary to determine the physiographic features as well as hydraulic and hydrologic features of basins and streams to manage water quality effectively. Also, accurate evaluation and prediction of pollutant inflow to streams are important. Therefore, there is a need for ILBM to monitor current status, changes and to predict future conditions of the Korean basin environment.

The object of this research is to analyze the water quality improvement of Lake Paldang by implementing Integrated Lake Basin Management (ILBM). To establish ILBM, the basin environment database was built as well as water environment management support system for monitoring current conditions and predicting changes in basin environment. The major contaminants in Lake Paldang Basin are from domestic pollution, agricultural land, and livestock. Scenarios for reducing contaminants were targeting the increase percentage of sewered population, agricultural and livestock contaminants reduction to analyze the water quality improvement effects.

2. Methodology

2.1 Study Area

Lake Paldang Basin was selected as the study area which is a water source for 46% (23 million) of the Korean population (Fig. 1). It is important to manage the water quality of Bukhangang River Basin, Namhangang River Basin and Gyeongancheon River Basin that flow into Lake Paldang. The Lake Paldang Basin includes the areas of Lake Paldang, Bukhangang River Basin, Namhangang River Basin and Gyeongancheon River Basin. Bukhangang River Basin partially includes North Korean territory which occupies 13% of the entire Lake Paldang Basin area. It is considered to be necessary to include all three river basins (Bukhangang River, Namhangang River and Gyeongancheon River) in this study. The Lake Paldang is an artificial Lake created by the Paldang dam between the Bongan Tunnel in Neungnae 2-ri, Joan-myeon, Namyangju-si and Yongdamsa Temple in Baealmi-dong, Hanam-si in 1973. The impoundment of Lake Paldang is 244 million tons, and water source supply capacity is 78 million tons/day (PWQIC, 2011). Three big basins, Bukhangang River basin (Including North Korea), Namhangang River basin and Gyeongancheon River basin, meet at the Lake Paldang. The total population at the Lake Paldang Basin is 2.3 million and the percentage of the sewered population is 67.7% (ME, 2008a).

2.2 SWAT Model and Creation of Dataset

To improve the water quality of lake basins, it is required to collect, organize and integrate environmental data in basin units. All available environmental data were collected and organized by local governments or administrative agencies, but there is insufficient use of such data to improve the water quality environment. To determine the current status of the basin environment, its database was established using the Geographical Information System (GIS). The GIS consists of the graphic data representing spatial locations connected to related attribute data, and it can be defined as an integrated system of hardware, software, geographical data and human resources used to efficiently collect, preserve, renew, process, analyze and output various forms of geographical information. The Soil and Water Assessment Tool (SWAT 2009) was selected as the basin model. The SWAT model is a Continuous Rainfall-Runoff Model developed by Jeff Arnold (Arnold *et al*., 1990) of the United States Department of Agriculture, Agricultural Research Service (USDA, ARS) to predict runoff of big and complicated basins and non-point pollution sources at ungauged basins according to various long-term soil attributes and land use as well as changes in the

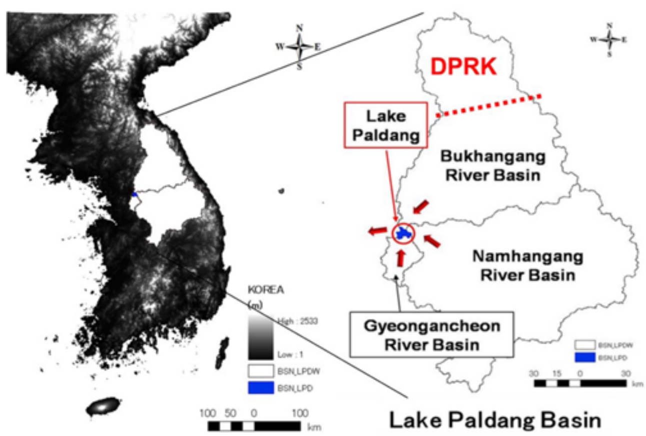


Fig. 1. Lake Paldang Basin in Korea

management state. The SWAT model applies basin environment data to the physical process related to hydrologic and water quality phenomena in the basin, predicts stream hydraulics and water quality, estimates point and non-point pollution loads in the basin, predicts water pollutant reduction effects and simulates waterside greenbelts (Arnold et al., 1990).

Figure 2 shows the input and output process of basin environment data in the SWAT model. The input data consist of meteorological data such as the amount of precipitation, maximum and minimum temperatures, relative humidity, wind velocity, and insolation, and basin data such as DEM, land use, and soil. Moreover, it is necessary to input vegetation data to estimate emission loads of point and non-point pollutant sources (Ahn et al., 2010). This study established the basin environment database of Lake Paldang Basin in Korea using DEM, land use, soil, meteorological data and hydrological data (Table 1).

2.3 Calibration and Validation using SWAT Model

This study conducted the simulation of flow rate, SS, TN and TP with the SWAT model using the basin environment database. Surface runoff has a great effect on nitrogen and phosphorus which adsorbed onto solid matters. Thus, the calibration and validation were done in order of SS, TN and TP. The target period was from January 1, 2002 to December 31, 2009. The test run period was from January 1, 2002 to December 31, 2005; the calibration period was from January 1, 2006 to December 31, 2007; and the validation period was from January 1, 2008 to December 31, 2009. The outflow was determined by discharge the water from Paldang dam when it rained. Therefore, it was assumed that all the dams in upstream were operated with similar conditions. Paldang Dam's flux data was taken for calibration of parameters of all basins since Paldang Dam is the last dewatering outlet of Lake Paldang Basin.

To assess the accuracy and correlation of the simulation results on measurement values, this study calculated % difference (Eq. (1)) (ASCE, 1993), NSE (Nash-Sutcliffe efficiency) (Eq. (2)) (Nash and Sutcliffe, 1970), Coefficient of Determination (R2) and RMSE (Root Mean Square Error) (Eq. (3)) (Donigian, 2000).

$$\%\ difference = \left(\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i\right) \Big/ \sum_{i=1}^{n} O_i \times 100 \qquad (1)$$

$$NSE = 1 - \sum_{i=1}^{n}(O_i - P_i)^2 \Big/ \sum_{i=1}^{n}(O_i - \bar{O}_l)^2 \qquad (2)$$

$$RMSE = \frac{1}{n}\sqrt{\sum_{i=1}^{n}(O_i - P_i)^2} \qquad (3)$$

n = Number of data
O_i = Measurement values
$\bar{O}_l$ = Average of measurement values
P_i = Simulation values

% difference is the statistical method to mathematically compare the measurement values with simulation values, indicating the quantitative index that represents the reliability of the measurement in which the same results are expected and repeated. NSE is the index representing suitability of the measurement and simulation values, indicating that, if the values are between 0 and 1.0, it is possible to use the simulation results based on the average of the measurement data. RMSE is the basis to calculate the mutual deviation of the measurement data similar to the statistical standard deviation and the simulation results (Table 2).

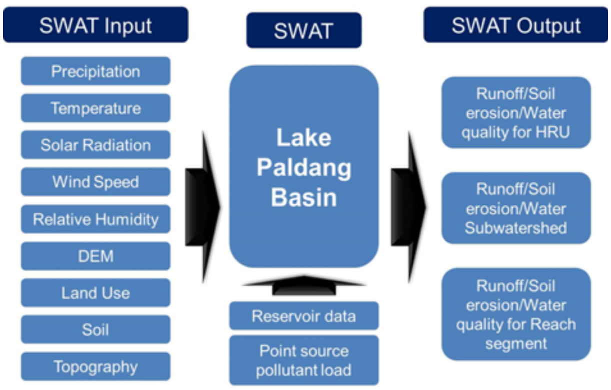


Fig. 2. Construction of SWAT Model

Table 1. Basin Environmental Database and Data Source

Basin Environmental Database	Data Source
Digital Elevation Model	National Geographic Information Institute, Consultative Group on International Agricultural Research-Consortium for Spatial Information
Land Cover/Land Use	Environmental Geographic Information System, U.S. Geological Survey
Soil	Waterbase
Weather Generator Gage Location	Korea Meteorological Administration
Precipitation Daily Data	
Temperature Daily Data	
Solar Radiation Daily Data	
Wind Speed Daily Data	
Relative Humidity Daily Data	
Point Source Data	Water Management Information System
Water Quality Data	Water Resources Management Information System
Population Data	Statistics Korea

2.4 Analysis of Water Quality Improvement Effects on Lake Paldang

To predict the improvement in water quality of Lake Paldang Basin, water pollutants were determined and their reduction scenarios were made accordingly. Based on the basin environment database, water pollutants from domestic, land and livestock were the main pollution sources. The pollutant loads of SS are 121,120 ton/year from agricultural pollution sources, 106,014 ton/year from livestock pollution sources, domestic use 69,148 ton/year, industry 4,065 ton/year, and total of 300,346 ton/year in

Table 2. General Simulation Targets and Tolerances for SWAT Application

Evaluation	Very good	Good	Fair	Poor
% difference				
Water flow	< 10	10-15	15-25	-
Sediment	< 20	20-30	30-45	-
Nutrients	< 15	15-25	25-35	-
NSE & R^2				
Water flow	> 0.80	0.80-0.70	0.70-0.60	0.60 <
Sediment	> 0.80	0.80-0.70	0.70-0.60	0.60 <
Nutrients	> 0.80	0.80-0.70	0.70-0.60	0.60 <

the Lake Paldang. The pollutant loads of TN are 76,660 ton/year from agricultural pollution sources, livestock 49,293 ton/year, 24,694 on/year from domestic use, 2,711 ton/year from industry, and total of 153,358 ton/year. The pollutant loads of TP are 2,083 ton/year from agricultural pollution sources, livestock 3,342 ton/year, 927 ton/year from domestic use, 78 ton/year from industry, and total of 153,358 ton/year. The water pollution sources in Lake Paldang are agricultural land, livestock and domestic use. Since industrial pollution source in Lake Paldang Basin only captures 1% of SS and TP and 2 % of TN of total pollution sources, it was not included. Therefore, the scenarios for reducing water pollution sources were selected as follows: increasing the percentage of sewered population, and reducing agricultural and livestock pollution sources. The total population at Lake Paldang Basin is 2,320,495, and the percentage of the sewered population is 67.7% (ME, 2008a). Since the non-sewered population takes up 32.3%, domestic pollution sources flowed in by Lake Paldang Basin can be reduced by supplying sewerage. The pollution loads emitted by agricultural lands are SS 40%, TN 52% and TP 50%, and the loads of livestock pollutant sources are SS 35%, TN 32% and TP 32%, taking up most of the pollution loads emitted from the entire basin. Therefore, the following scenarios are set for water quality improvement.

Scenario 1: Increasing the percentage of sewered population
Scenario 2: Reducing agricultural pollution sources
Scenario 3: Reducing livestock pollution sources
Scenario 4: Increasing the percentage of sewered population and reducing agricultural pollution sources
Scenario 5: Increasing the percentage of sewered population and reducing livestock pollution sources
Scenario 6: Reducing agricultural pollution sources and livestock pollution sources
Scenario 7: Increasing the percentage of sewered population, and reducing agricultural pollution sources and livestock pollution sources

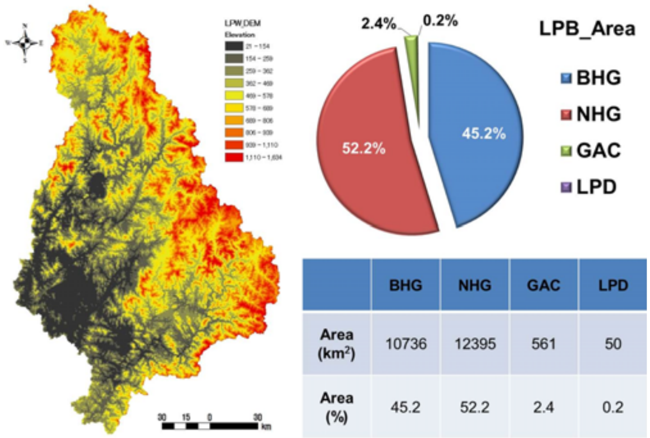
Scenario 1 is the plan to increase the percentage of the population connected to and using sewer systems. The percentage of the sewered population in Korea is 90%, and thus the plan was to increase the percentage of sewered population at Lake Paldang Basin to 90%. This study attempted to increase the efficiency of sewage treatment by installing an extra facility of advanced wastewater treatment and expand the infrastructure in Lake Paldang Basin. The efficiency of WWTP in Korea is SS 80-95% and TN and TP are 40-60% (ME, 2008b). Scenario 2 is the plan to reduce agricultural pollution sources, reducing the standard amount of fertilizers by agricultural reuse of sewage treatment plant effluents. Korea Ministry of Science and Technology reported that reusing WWTP effluents as agricultural water could gain the same yield as using 40% of the amount of applied fertilizers (MST, 2006). Currently, researches regarding the reuse of WWTP effluents are being conducted therefore it is assumed 60% of fertilizers could be reduced. Scenario 3 is the plan to reduce livestock pollution sources. These livestock pollution sources can be reduced by extending basic environmental facilities at Lake Paldang Basin and additionally installing advanced wastewater treatment facilities. The sewage treatment efficiency in Korea is 80-95% for SS and 40-60% for nutritive salts (ME, 2008b). This study assumed that SS, TN and TP treatment efficiencies would be increased 50% more from current efficiencies. Scenario 4 applied measures to increase the percentage of sewered population and reduce agricultural pollution sources, Scenario 5 applied measures to increase the percentage of sewered population and reduce livestock pollution sources, and Scenario 6 applied measures to reduce agricultural and livestock pollution sources. Scenario 7 applied all scenarios mentioned in Scenarios 1-3 to analyze the improvement in water quality.

3. Results and Discussion

3.1 Basin Environmental Database

Figure 3 shows the DEM of Lake Paldang Basin. The DEM was established using the 1:25,000 numerical maps provided by the National Geographic Information Institute and the digital elevation data of the Consultative Group on International Agricultural Research-Consortium for Spatial Information (CGIAR-CSI). Lake Paldang Basin has a maximum altitude of 1,634 m, minimum altitude of 21 m, and average altitude of 471 m. LPB means Lake Paldang Basin, BHG is Bukhangang River Basin, NHG is Namhangang River Basin, GAC is Gyeongancheon River Basin and LPD means Lake Paldang. The Lake Paldang Basin can be divided into Bukhangang River Basin, Namhangang River Basin and Gyeongancheon River Basin. The area of Lake Paldang Basin is 23,741 km^2, of which Namhangang River Basin accounts for 52.2% (12,395 km^2), Bukhangang River Basin 45.2% (10,736 km^2), and Gyeongancheon River Basin is 2.4% (561 km^2).

For landuse, the 1:25,000-resolution medium classification land cover degree provided by the Environmental Geographic Information System (EGIS) and the GLCC (Global Land Cover Characterization) data of the USGS (U.S. Geological Survey) were used. To establish the basin model, the areas with similar soil characteristics are classified by HRU, based on which the runoff calculation is simulated; thus, soil map and soil characteristics



	BHG	NHG	GAC	LPD
Area (km²)	10736	12395	561	50
Area (%)	45.2	52.2	2.4	0.2

Fig. 3. Digital Elevation Model Database of the Lake Paldang Basin in Korea

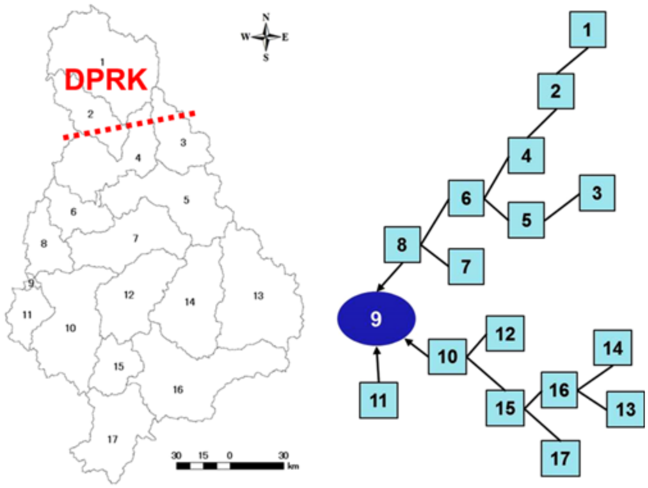
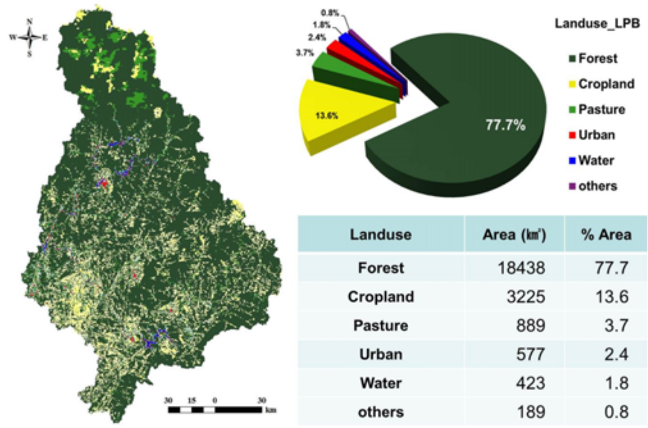


Fig. 5. Subbasins division of the Lake Paldang Basin in Korea



Landuse	Area (㎢)	% Area
Forest	18438	77.7
Cropland	3225	13.6
Pasture	889	3.7
Urban	577	2.4
Water	423	1.8
others	189	0.8

Fig. 4. Land use Database of the Lake Paldang Basin in Korea

data must be established and overlaid. For the soil of Lake Paldang Basin, a soil map of the water base and soil characteristics data were used. Fig. 4 show landuse database. Landuse of the Lake Paldang Basin consists of forest 77.7% (18,438 km^2), cropland 13.6% (3,225 km^2), pasture 3.7% (889 km^2), and urban area 2.4% (577 km^2). Soil consists of loam 51.5% and sandy loam 48.5%.

Figure 5 shows subbasins division of the Lake Paldang Basin in Korea. Based on the DEM, the basin is divided into multiple sub-basins by forming links among them. Each sub-basin consists of climate, Hydrologic Response Units (HRU), pond/wetland, groundwater, and stream. HRU is the land in the sub-basin classified by land use, soil and soil management type, and individual parameters related to hydrologic phenomena are set on each HRU. The hydrologic phenomena of the sub-basins were calculated using such data. The hydrologic phenomena of the waters were simulated in the stream, and flow rate, suspended solids, and nutritive salts from the sub-basins were also calculated. These results were applied to the waters of the downstream subbasins, ultimately simulating the hydrologic and water quality phenomena of the entire basin (Eckhardta and Arnold, 2001). Lake Paldang Basin was divided into 17 subbasins and database was created accordingly, and 384 HRU were defined using SWAT Model.

For meteorological data, the daily meteorological data (wind velocity, temperature, maximum temperature, minimum temperature, humidity, insolation, amount of precipitation) was taken, which was observed from January 1, 2001 to December 31, 2010 at the weather observation point of Lake Paldang Basin. The amount of radiation was only observed at the meteorological stations of Daegwallyeong, Chuncheon, Wonju, Suwon, and Cheongju, and thus the data from these observation points were used. There were 17 observation points at Lake Paldang Basin: Cheorwon, Daegwallyeong, Chuncheon, Wonju, Suwon, Yeongwol, Chungju, Cheongju, Yangpyeong, Icheon, Inje, Hongcheon, Taebaek, Jecheon, Boeun, Bonghwa, and Yeongju.

The SWAT calibration compares simulation values with measurement values to determine the optimum parameter. To this end, the measurement values of Lake Paldang Basin such as flow rate and pollution load were collected. The daily outflow of Paldang Dam was used as flow rate data. Measurement values were collected using water quality measurement data provided by the Ministry of Environment's water environment information system.

3.2 Calibration and Validation using SWAT Model

Table 3 shows the calibration and validation results using the SWAT model. Flow rate was calibrated from runoff, base runoff and groundwater-related factors. To evaluate the applicability of the model, % difference, NSE, coefficient of determination and RMSE of the daily flow rate of Lake Paldang were calculated (Table 2). Calibration results were as follows: % difference 13.7%, NSE 0.80 ('Good'), coefficient of determination 0.81, and RMSE 25. It seems that for flow rate, the model well reflected the tendency of the measured flow rate (Donigian, 2000). Nitrogen and phosphorus absorbed by suspended solids are greatly affected by the rain, and thus calibration and validation were

Table 3. Calibration & Validation Results for SWAT Model

Evaluation	Calibration				Validation			
	% difference	NSE	R^2	RMSE	% difference	NSE	R^2	RMSE
Water flow	13.7	0.80	0.81	25	12.4	0.71	0.72	19.4
SS	13.5	0.80	0.81	9	12.7	0.71	0.71	7
TN	17.7	0.71	0.77	5	16.6	0.71	0.71	3
TP	26.2	0.65	0.71	0.3	34.3	0.65	0.68	0.2

carried out in the order of SS, TN and TP. The SS calibration, it was evaluated as 'Good', with the simulation value similar to the measurement value. Nitrogen has various response mechanisms such as nitrification, denitrification and nitrogen fixation, and mostly exists in the form of NO_3-N in agricultural lands. Unlike nitrogen, phosphorus is not easily dissolved in water but is mostly absorbed by the soil, running off along with soil; thus, it is necessary to consider the complicated response mechanisms of the basin. TN was 'Good' with % difference 17.7% and coefficient of determination 0.77; and TP was 'Fair' with % difference 26.2% and coefficient of determination 0.71. As a result of the validation, flow rate was 'Good' with % difference 12.4% and NSE 0.71, and coefficient of determination 0.72 and RMSE 19, showing a high correlation between measurement data and simulation results. Moreover, SS was 'Good' with % difference 12.7% and coefficient of determination 0.71, TN was 'Good' with % difference 16.6% and coefficient of determination 0.71, and TP was 'Fair' with % difference 34.3% and coefficient of determination 0.68.

This study applied the SWAT model to Lake Paldang Basin using the basin environment database to improve the water quality of Lake Paldang in Korea. The results of calibration and validation of flow rate, SS, TN and TP showed that the measurement values and simulation values turned out to be similar, and that it is possible to apply the SWAT model to Lake Paldang Basin.

3.3 Effect analysis of Water Quality Improvement at Lake Paldang Basin

This study analyzed the effects of the seven water quality improvement plans, such as increasing the percentage of the sewered population, reducing agricultural pollution sources, and reducing livestock pollution sources. For the effect analysis of each scenario to improve the water quality of Lake Paldang, the annual pollution emissions were analyzed, and the reduction effects of each scenario were compared. Table 4 shows the simulation results before and after applying the scenarios. The reduction efficiency of SS by scenario was 11-45%, TN 8-37%, and TP 7-35%, indicating that there were greater water quality improvement effects compared to before application.

Scenario 1 had the effect of reducing SS by 11%, TN by 8%, and TP by 7%. Scenario 2 had the effect of reducing SS by 16%, TN by 20% and TP by 13%, representing the greatest TN reduction effect among the single scenarios for water quality improvement. Controlling nutrients by reducing use of chemical fertilizers in agricultural land is recommended the Korea government for non-point source pollutants control in rural area (Jang *et al.,* 2012). Scenario 3 had the effect of reducing SS by 17%, TN by 9% and TP by 15%, with high reduction effects in relation to SS and TP. In Lake Paldang Basin where the agriculture and livestock industry are active, it seems important to improve water quality through the management of livestock pollution sources. Advanced wastewater treatment facilities are being installed to existing WWTP by Korea Ministry of Environment, for reducing nitrogen and phosphorus in effluent.

Scenario 4 had the effect of reducing SS by 27%, TN by 28% and TP by 20%, and Scenario 5 had the effect of reducing SS by 29%, TN by 17% and TP by 22%. Scenario 6 had the effect of reducing SS by 33%, TN by 29% and TP by 28%. Scenario 7 had the effect of reducing SS by 45%, TN by 37% and TP by 35%. To effectively improve water quality, it is necessary to consider water quality management measures for both point and non-point pollutant sources. Significant water quality improvement effects in regard to Lake Paldang were brought about through the plan of reducing agricultural and livestock pollution sources. Substantial improvement in water quality in Lake Paldang can be achieved by reduction of agricultural and livestock pollution sources. Reducing the amount of applied fertilizers in agricultural lands is effective for controlling nutritive salts. It seems necessary to establish basic environmental facilities to reduce livestock pollution sources.

As a result of analyzing the effects of each scenario to improve the water quality of Lake Paldang (Table 4), increasing the percentage of the sewered population (Scenario 1) resulted in the improvement of SS to 8.42 mg/L, TN to 4.47 mg/L and TP to 0.217 mg/L. Reducing agricultural pollution sources (Scenario 2) resulted in the improvement of SS to the level of 7.98 mg/L, TN to 3.89 mg/L and TP 0.204 to mg/L, and reducing livestock pollution sources (Scenario 3) resulted in the improvement of SS to the level of 7.84 mg/L, TN to 4.39 mg/L and TP to 0.204 mg/L. The reduction plan that considered both agricultural and livestock pollution sources (Scenario 6) resulted in the improvement of SS to 6.30 mg/L, TN to 3.42 mg/L and TP to 0.167 mg/L, and the reduction plan that applied all scenarios (Scenario 7) resulted in the improvement of SS to 5.21 mg/L, TN to 3.03 mg/L and TP to 0.150 mg/L. Therefore, ILBM must be implemented in order to improve water quality in the lake basin.

4. Conclusions

This study analyzed the effects of different scenarios to improve the water quality of Lake Paldang in order to implement

Table 4. The Contribution of Pollutant Load and Water Qualities

	SS			TN			TP		
	TPL[a]	RR[b]	Conc.[c]	TPL[a]	RR[b]	Conc.[c]	TPL[a]	RR[b]	Conc.[c]
Current	3.00	-	9.52	1.53	-	4.86	6.43	-	0.234
Scenario 1	2.66	11.5	8.42	1.41	8.1	4.47	5.97	7.2	0.217
Scenario 2	2.52	16.1	7.98	1.23	**20.0**	3.89	5.60	13.0	0.204
Scenario 3	2.47	**17.6**	7.84	1.39	9.6	4.39	5.43	**15.6**	0.198
Scenario 4	2.17	27.6	6.89	1.10	28.0	3.50	5.13	20.2	0.187
Scenario 5	2.13	29.2	6.74	1.26	17.7	4.00	4.96	22.8	0.181
Scenario 6	1.99	**33.8**	6.30	1.08	**29.6**	3.42	4.59	**28.6**	0.167
Scenario 7	1.64	**45.3**	5.21	0.96	**37.7**	3.03	4.13	**35.8**	0.150

[a] : Average Total Pollutant Load (SS: 10^5 ton/year, TN: 10^4 ton/year, TP: 10^3 ton/year)
[b] : Average Reduction Rate (%)
[c] : Average Concentration (mg/L)

ILBM in Korea. To establish ILBM, the basin environment database was built as well as water environment management support system for monitoring present conditions, and predicting changes in basin environment. The major contaminants in Lake Paldang Basin are from domestic use, agricultural land, and livestock. Scenarios for reducing contaminants were targeting the increase percentage of sewered population, agricultural and livestock contaminants reduction to analyze the water quality improvement effects. The results can be summarized as follows.

1. As a result of calculating the model assessment indexes by calibration and validation of flow rate, SS, TN and TP, it was found that the simulation values well reflected the measurement values, and qualitative and quantitative assessments of Lake Paldang Basin can be made.
2. The SWAT model application for the water quality improvement analyzed the following options: increasing the percentage of the sewered population (Scenario 1), reducing agricultural pollution sources through agricultural reuse of sewage treatment plant effluents (Scenario 2), and reducing livestock pollution sources by extending basic environmental facilities and additionally installing advanced wastewater treatment facilities (Scenario 3). This study also analyzed the water quality improvement of scenarios that combined Scenarios 1, 2, 3 (Scenarios 4-7). The reduction efficiency of SS by scenario was 11-45%, TN 8-37%, and TP 7-35%, indicating that there were greater water quality improvement effects compared prior to application.
3. Scenario 2 demonstrated the efficiency of reducing SS by 16%, TP by 13%, and TN by 20% which is the greatest TN reduction effect among all single scenario. Scenario 3 had the effect of reducing SS by 17%, TN by 9% and TP by 15%, with high reduction effects in relation to SS and TP. Reducing the amount of applied fertilizers in agricultural lands is effective for controlling nutritive salts, and it seems necessary to establish basic environmental facilities to reduce livestock pollution sources.
4. The results of ILBM assessment of Lake Paldang Basin showed that the plan to reduce agricultural and livestock pollution sources (Scenario 6) had the effect of reducing SS by 33%, TN by 29% and TP by 28%. The reduction plan that was applied to all scenarios had the effect of reducing SS by 45%, TN by 37% and TP by 35%. It turned out that reducing agricultural and livestock pollution sources has great water quality improvement effects at Lake Paldang. In Lake Paldang Basin where the agriculture and livestock industry are active, it seems significant to improve water quality through the management of livestock pollution sources.
5. As a result of analyzing the effects of each scenario to improve the water quality of Lake Paldang, the reduction plan that considered both agricultural and livestock pollution sources (Scenario 6) resulted in the improvement of SS to the level of 6.30 mg/L, TN to 3.42 mg/L and TP to 0.167 mg/L, and the reduction plan that applied all scenarios (Scenario 7) resulted in the improvement of SS to the level of 5.21 mg/L, TN to 3.03 mg/L and TP to 0.150 mg/L. Therefore, ILBM must be implemented in order to improve water quality in the lake basin.

The applicability of the SWAT model has been widely demonstrated in basin management. To increase the reliability of results, it is necessary to establish an accurate model based on a sufficient basin environment database of the target basin, and conduct continuous research to verify the results of this study. It is also necessary to conduct research that considers the economic aspects of each scenario to come up with efficient measures to reduce pollution loads in basins with severe pollution.

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References

Ahn, J., Hong, Y., Kang, H., Kim, H., Han, D., Jang, J., Seo, D., and Park, Y. (2010). "Water quality management strategy in the context of climate change I." *Korea Environment Institute, Republic of Korea*, pp. 112-116.

Arnold, J. G., Williams, J. R., Nicks, A. D., and Sammons, N. B. (1990). "SWRRB: A basin scale simulation model for soil and water resources management." *Texas A&M Univ. Press, College Station*, TX.

ASCE (1993). "ASCE Task committee on definition of criteria for evaluation of watershed models of the watershed management committee." *Irrigation Drainage Engineering,* Vol. 119, No. 3, pp. 429-442.

Consultative Group on International Agricultural Research-Consortium for Spatial Information (CGIAR-CSI), http://www.cgiar-csi.org.

Donigian, A. S. Jr. (2000). HSPF Training Workshop Handbook and CD. Lecture #19, Calibration and Verification Issues, Slide #L19-22, EPA Headquarters, Washington Information Center, 10-14 January, 2000, Presented and prepared for U.S. EPA, Office of Water, Office of Science and Technology, Washington, D.C.

Eckhardta, K. and Arnold, J. G. (2001). "Automatic calibration of a distributed catchment model." *Journal of Hydrology*, Vol. 251, Nos. 1-2, pp. 103-109, DOI: 10.1016/S0022-1694(01)00429-2.

Environmental Geographic Information System (EGIS), http://egis.me.go.kr.

Global Water Partnership Technical Advisory Committee (GWP-TAC). (2000). *Integrated Water Resources Management*, TAC Background Papers, 4.

Hwang, J., Kim, Y., Kwon, J., Park, J., Noh, J., and Yi, Y. (2014), "Hydrodynamic and water quality modeling for gate operation: A case study for the Seonakdong River basin in Korea" *KSCE Journal of Civil Engineering*, KSCE, Vol. 18, No. 1, pp. 73-80, DOI: 10.1007/s12205-013-0025-6.

International Lake Environment Committee (ILEC) Foundation (2005). Managing Lakes and their Basins for Sustainable Use.

International Lake Environment Committee (ILEC) Foundation (2007). Global Environment Facility-Lake Basin Management Initiative Project.

Jang, J., Jung, K., and Yoon, C. (2012). "Modification of SWAT model for simulation of organic matter in Korean watersheds." *Water Science and Technology*, Vol. 66, No. 11, pp. 2355-2362, DOI: 10.2166/wst.2012.465.

Kang, B., Kim, Y., Lee, J., and Kim, S. (2015). "Hydro-environmental runoff projection under GCM scenario downscaled by Artificial Neural Network in the Namgang Dam watershed, Korea." *KSCE Journal of Civil Engineering*, KSCE, Vol. 19, No. 2, pp. 434-445, DOI: 10.1007/s12205-015-0580-0.

Korea Meteorological Administration (KMA), http://web.kma.go.kr.

Lee, D., Kim, J., Mendoza, J., Lee, C., and Kang, J. (2017). "Potential use of ionic species for identifying source land-uses of stormwater runoff." *Water Science and Technology*, Vol. 75, No. 4, pp. 978-986, DOI: 10.2166/wst.2016.575.

Millennium Ecosystem Assessment (MA). (2005). Ecosystems and Human Well-being: Synthesis.

Ministry of Environment (ME) (2008a). *Investigation of Pollution loading amount,* Republic of Korea.

Ministry of Environment (ME) (2008b). *Improvement Plan of Sewage*, Republic of Korea.

Ministry of Science and Technology (MST) (2006). *Sustainable Water Resources Research Program*, Republic of Korea.

Nash, J. E. and Sutcliffe, J. V. (1970). "River flow forecasting through conceptual models part I-A discussion of principles." *Journal of Hydrology*, Vol. 10, No. 3, pp. 282-290, DOI: 10.1016/0022-1694(70)90255-6.

National Geographic Information Institute (NGII), http://www.ngii.go.kr.

Paldang Water Quality Improvement Center (PWQIC). (2011). A white book of Paldang, Republic of Korea.

Park, M., Ha, R., Kim, N., Lim, K., and Kim, S. (2014). "Assessment of future climate and vegetation canopy change impacts on hydrological behavior of Chungju dam watershed using SWAT model." *KSCE Journal of Civil Engineering*, KSCE, Vol. 18, No. 4, pp. 1185-1196, DOI: 10.1007/s12205-013-0176-5.

Statistics Korea, http://sgis.kostat.go.kr.

U.S. Geological Survey Global Land Cover Characterization (USGS-GLCC), http://edc2.usgs.gov/glcc/glcc.php.

Waterbase, http://www.waterbase.org.

Water Resources Management Information System (WAMIS), http://www.wamis.go.kr.

Water Management Information System, http://water.nier.go.kr.