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Analysis of Water Quality improvement of Upper Stream for the Chung-ju Dam according to Reducing Pollution Using QUAL2E Model

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QUAL2E 모형을 이용한 오염원변화에 따른 충주댐 상류 유역의 수질 개선 효과 분석

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Abstract

The research grasps water quality contamination source by investigating the data that are superordinate laws and the related plans implemented for establishing water quality improvement measures of upper stream for Chung-Ju Dam, present conditions of the hydraulic and hydrology, the present conditions and plans of environment basic facilities, and present conditions of main contamination source's occurrence load and discharge load, etc. The research used the QUAL2E simulation which is being widely applied to simulation of river water quality because the QUAL2E has high credibility among water quality simulations known throughout the country. On basis of this research, regulations and politic alternatives are required in order to water quality improvement upper stream for the Chung-ju dam, especially establishing processing facilities in the region where loading amount is concentrated should be considered with the additional research regarding cost-efficient facility of pollution source.

Keywords *: Environment facility, Pollutant load, Pollution source, QUAL2E model, Water quality simulation*

요 약

본 연구는 충주댐 상류유역의 수질개선대책을 수립하기 위해 실시된 상위 및 관련계획, 수리·수문환경, 환경기초시설 현황 및 계획, 수질현황, 주요 오염원 발생 및 배출현황 등의 자료조사를 통하여 수질오염원을 파악하고 국내에 알려져 있는 수질모델 중 신뢰도가 인정되어 하천수질모의에 널리 적용되고 있는 QUAL2E 모형을 적용하였다. 연구 결과를 토대로 하여 충주댐 상류 유역의 수질개선을 위한 규제와 정책 방안들을 고려한 수질예측이 필요할 것으로 판단되며, 특히 충주댐 상류 유역의 오염원별 수질을 관리하는 방안과 더불어 오염원별 배출부하량이 높은 지역의 대형 환경기초시설에 의한 고도처리시설 도입 및 비점오염 저감시설에 의한 부분을 고려한 추가적인 연구가 필요할 것으로 판단된다.

핵심용어 : 환경기초시설, 오염원, 배출부하, 수질모의, QUAL2E 모형

1. Introduction

Various researches are being implemented for water quality improvement of rivers and lakes in water system as water quality management of the river is getting major concern due to rapid population growth, economic development, and citification(Gang et al., 1996; Gang and Yang, 1996; Gang and Hyeon, 1997; Lee et al., 2006; Kim et al., 2009; Park et al., 2011). Futhermore, water quality management of lake water which is mainly used for drinking water source is highly getting important according as social concern about drinking water increases. Especially, water quality management of the water in dam and the river water flowing into it that are generally used for service water in wide area will be conducted carefully in consideration of hydraulic properties on the lake which are deep and very slow in terms of the speed

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of a moving fluid(Kim, 2009). Futhermore, various phenomenons occurring in the river appear because of not problems at one spot but knock-on problems between upstream and downstream. Due to the reasons, overall establishment of management plans concerning not one spot but entire river basin is essential in order to use continually and develop water resources in the river. The change of water quality in water system induced by inflow of external contamination sources can be grasped by using mathematic model which is metrizable. Water quality is determined by the size of inflow pollution load, and pollutants in water system are changed by characteristics of foreign material which are chemical, biological, and also by physical characteristics in water system. Loading amount originated from contamination source is grasped by concentration through water quality model, which is compared and checked with water criteria needed for water usage. It is necessary that water quality management measures will get established by finding various methods, in case of exceeding objective for water criteria. A commercialized model is properly being used for establishing measures and investigating those phenomena(Chapra, 1997).

The research grasps water quality contamination source by investigating the data that are superordinate laws and the related plans implemented for establishing water quality improvement measures of upper stream for Chung-Ju Dam, present conditions of the hydraulic and hydrology, the present conditions and plans of environment basic facilities, and present conditions of main contamination source's occurrence load and discharge load, etc. The research used the QUAL2E simulation which is being widely applied to simulation of river water quality because the QUAL2E has high credibility among water quality simulations known throughout the country(Tolman, 1992; DeGasperi and Khangaonkar, 1996; Venter et al., 1997; Ning et al., 2001; McAvoy et al., 2003).

Therefore, the research analyses and examines the prediction and impact of water quality improvement effect which are induced by constructing environmental basic facilities and reducing contamination source in upper stream basin for Chung-ju dam.

2. Method of study

The behavior of pollutant and pollution load in pertinent basin shoule be grasped for future water quality prediction using the model. For the sake of them, water quality and results of discharge measurement must be secured. The rate of flow is basic respect of calculating inflow concentration by inflowing contamination source in the basin, but measuring network of rate of flow that can precisely calculate the rate of flow in the pertinent basin for managing pollutants isn't presently constructed. The existing measuring network of the rate of flow is mainly aimed at flood control of a flood season in summer and don't almost accord with location of measuring network of water quality, so it is less likely to utilize data for grasping the effects of river's inflow of contamination source.

This research simulated to construct environment basic facilities and water quality during pondage according to reducing contamination source by using QUAL2E model. It calculated the rate of flow by basin using runoff block diagram of natural rate of flow that is existing investigated for constructing the rate of flow data which are aimed at grasping the influence induced by inflow of contamination source; moreover, it calculated inflow concentration by inflow of contamination source by basins using data between the basic year(2009) and the prediction year(2015): the current state of contamination source, rate of flow, water quality, occurrence load and discharge load, flow duration analysis. The research constructed the input data of QUAL2E model using data that are water quality by basin, rate of flow, environment basic facilities, and pollution load.

It conducted calibration and verification of the model using the data on the rate of flow and water quality in March~April(calibration) and October~November (verification) that have conditions comparatively having less of an effect on rainfall and being close to dry season. It implemented the model establishing virtual scenario according to existence of environment basic facilities for predicting the effect of water quality improvement by the change of contamination source in upper stream basin of Chung-ju dam.

2.1. Outline of QUAL2E model

The QUAL2E model is a model of water quality which can be normally applied to interpreting one-dimensional water quality in the river; it can simulate the 13 water contamination factors in the light of point pollution source, non-point pollution source, tributaries of the river, and water intake. etc. The most of water quality items are simulated as a steady state, but algae are simulated as a simular dynamic state. Material delivery movement in the river is described as the formula (1) by one-dimensional interpretation .

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}(D\frac{\partial C}{\partial x}) - \frac{\partial (UC)}{\partial x} + Z \qquad (1)$$

In this formula, C: contaminants concentration of cross section mean

D: longitudinal dispersion coefficient

U: mean flow velocity of cross section

Z: sinks, sources and internal change rate

The left term in the formula (1) means the rate of change of concentration for the time at any point, and the right terms respectively mean in order, longitudinal dispersion term, advection term, outflow and inflow term including biochemical reaction between each of contaminations.

The formula in case of the steady state means $\partial C/\partial t = 0$.

Hydro condition in the river is interpreted as steady non-uniform flow, and hydrometric data such as the rate of flow, flow velocity, and depth of water, etc. are calculated as the formulas (2) or (3).

$$U = aQ^b, \quad h = \alpha Q^\beta \qquad (2)$$

$$Q = \frac{1}{n} A_x R^{2/3} S^{1/2} \qquad (3)$$

In those formulas, a, b, α, β : coefficient of discharge in the section of the river

h: mean depth

U: mean velocity

Q: rate of flow

A_x: cross sectional area of flow

R: hydraulic radius

S: energy inclination

n: coefficient of roughness in Manning

a, b, α, β in the formula (2) are calculated by a correlation, and the formula (3) is calculated by the formula of Newton-Raphson according to the formula of Manning on mean velocity and rate of flow for cross section of trapezoidal channel(Kim, 2009).

2.2. Sectionalization of target basin

The research departmentalized the target basin into each of elements which measures 2km, and sectionalized the target basin which measures 170km from the upper stream basin for Nam Han River to the lower basin of Ok-Dong Stream into total 7 sections(Reach) on basis of hydrologic unit map.

2.3 The rate of flow and the present condition of water quality in upper stream basin of Chung-Ju Dam

The input data of rate of flow in this research are standard rate of flow based on the average data of discharge in Chung ju dam in March-April(2009) and October-November(2009) that have conditions of rate of flow comparatively having less of an effect on rainfall and being close to dry season. The input data divided the rate of flow by each of the sections for area ratio of occupation basin. It calculated delivery ratio using the data which are the rate of flow and water quality in March-April(2009) and October-November(2009), and is used for conducting calibration and verification of the model.

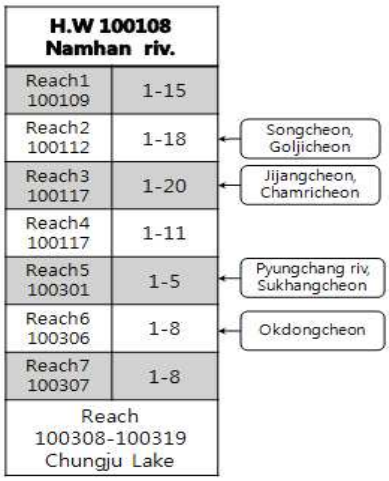


Fig. 1. Channel reach of QUAL2E model

Table 1. Runoff from Chung-Ju Dam(2009, unit : ㎥/s)

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dem	Avg.
2009	69.37	57.19	65.45	65.85	69.94	81.13	677.76	162.29	72.29	59.54	63.33	70.40	127.21

Table 2. Result of Flow Duration Analysis by PRMS(36 Year Average) (unit : ㎥/s)

Runoff basins		Average	Max flow (95 days)	Avg flow (185 days)	Low flow (275 days)	Min flow (355 days)
Watershed	area(㎢)					
Namhan riv.	2,447.9	54.03	44.87	24.78	14.96	7.67
Pyungchang riv.	1,773.4	39.85	22.37	13.72	9.33	5.95
Chungjoo Dam	2,483.8	43.22	25.62	15.70	10.43	6.41
Total	6,705.1	137.1	92.86	54.2	34.72	20.03

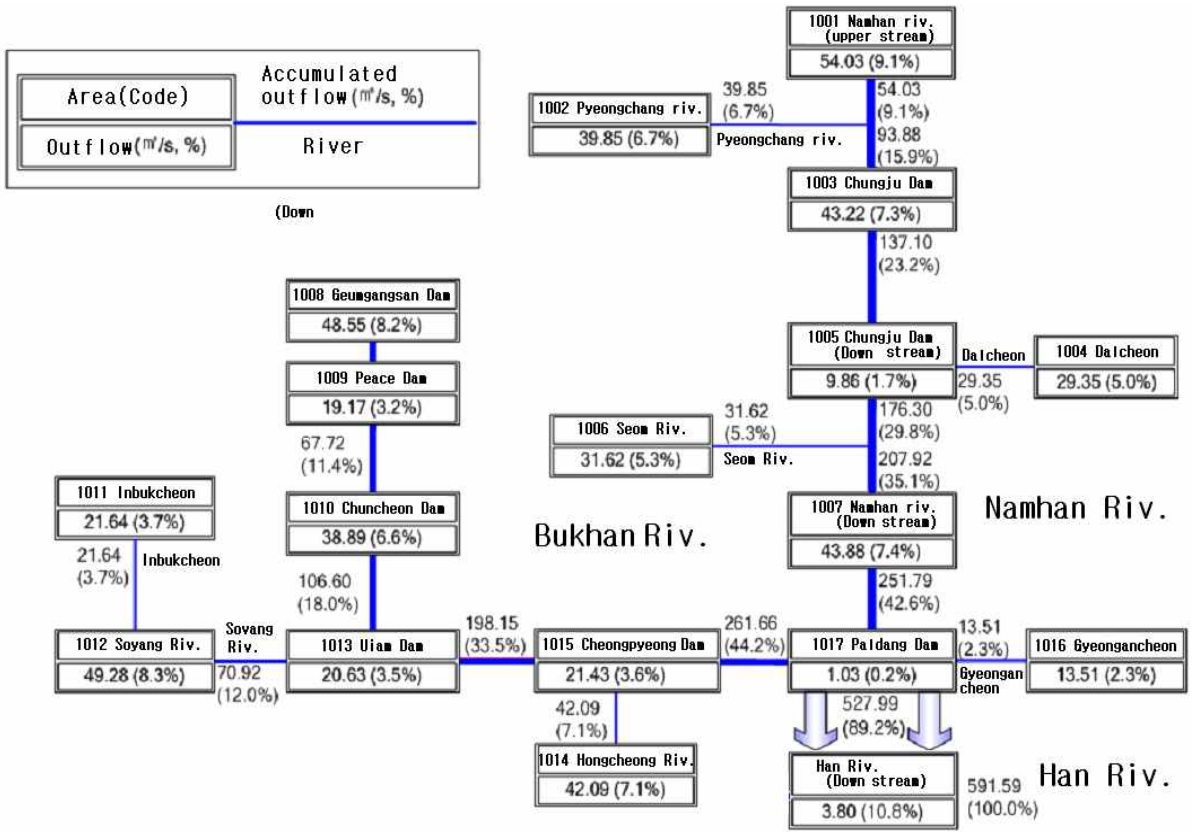


Fig. 2. Natural Flow Runoff Map of Chung-ju Dam

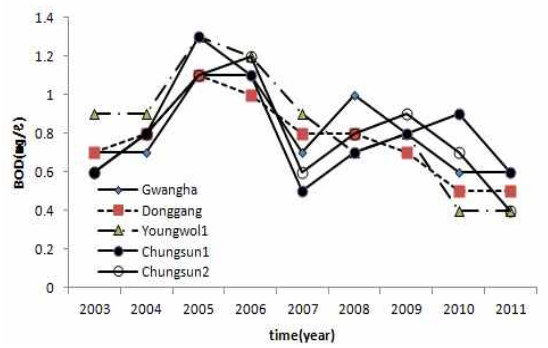
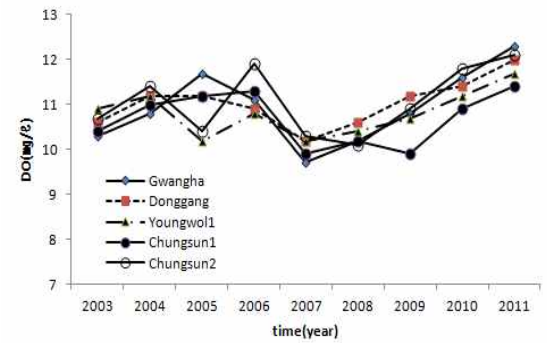
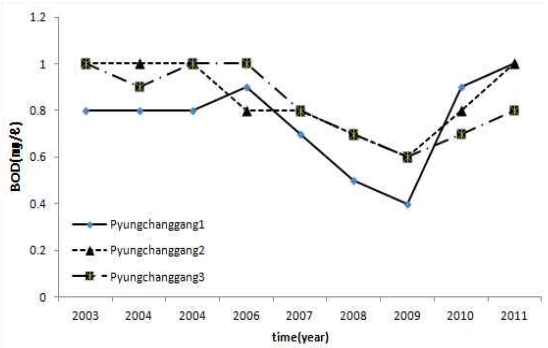
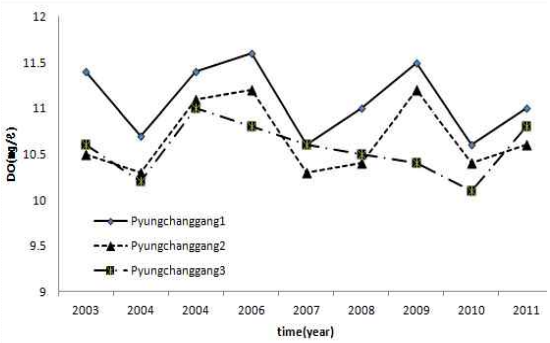
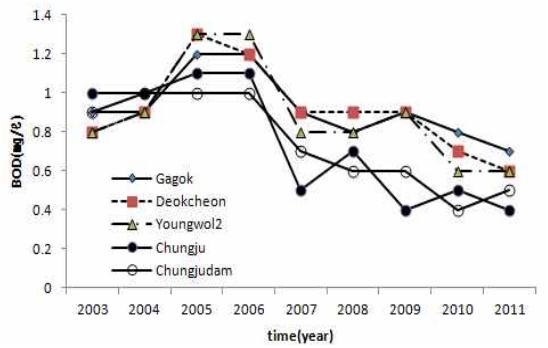
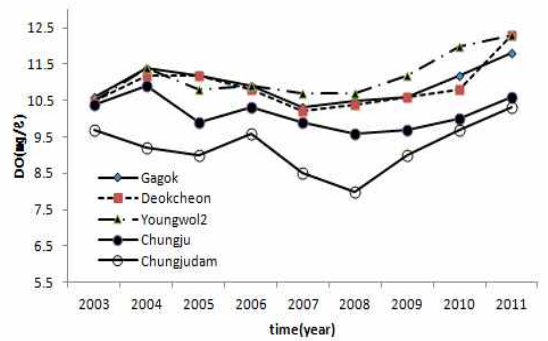
Area	Nam-han river	Place	Chung-sun1, Chung-sun2, Gwang-ha, Dongang, Young-wol1
BOD(Biological Oxygen Demand)		DO(Dissolved Oxygen)	
			
Area	Pyung-chang river	Place	Pyung_chang gang1, 2, 3
BOD(Biological Oxygen Demand)		DO(Dissolved Oxygen)	
			
Area	Chung-ju dam	Place	Young-wol2, Ga-gok, Deok-cheon, Chungjudam, Chungju
BOD(Biological Oxygen Demand)		DO(Dissolved Oxygen)	
			

Fig. 3. Characteristics of Water Quality in the Area

2.4 The present condition of water quality in upper stream basin of Chung-ju Dam

Administrative districts of upper stream basin in Chung-Ju Dam consist of Gangwon-do, Gyeongsangbuk-do, and Chungcheongbuk-do, which consist of the total 14 Si-Gun-Gu and 71 Up-Myun-Dong; it consist of 3 Middle Zone. The present condition of water quality in

the basin present that the BOD in upper stream basin of Nam Han River was 0.6 ㎎/ℓ at Jeongseon 1 point in 2003, 0.5㎎/ℓ at Jeongseon 1 point in 2007, 0.6㎎/ℓ at Jeongseon 1 point in 2011, 0.7㎎/ℓat Gwangha point in 2003, 0.7㎎/ℓat Gwangha point in 2007, 0.6㎎/ℓat Gwangha point in 2011, 0.7㎎/ℓat Donggang point in 2003, 0.8㎎/ℓat Donggang point in 2007, 0.5㎎/ℓat Donggang point in 2011, 0.9㎎/ℓat Yeongwol point in 2003, 0.9㎎/ℓat Yeongwol point in 2007, and 0.4㎎/ℓ at Yeongwol point in 2011.

The DO was 10.4 ㎎/ℓJeongseon 1 point in 2003, 9.9 ㎎/ℓJeongseon 1 point in 2007, 11.4 ㎎/ℓJeongseon 1 point in 2011, 10.7 ㎎/ℓJeongseon 2 point in 2003, 10.3 ㎎/ℓ Jeongseon 2 point in 2007, 12.1 ㎎/ℓ Jeongseon 2 point in 2011, 10.3 ㎎/ℓat Gwangha point in 2003, 9.7 ㎎/ℓat Gwangha point in 2007, 12.3 ㎎/ℓ at Gwangha point in 2011, 10.6 ㎎/ℓat Donggang point in 2003, 10.2 ㎎/ℓat Donggang point in 2007, 12 ㎎/ℓ at Donggang point in 2011, 10.9 ㎎/ℓat Yeongwol 1 point in 2003, 10.2 ㎎/ℓat Yeongwol 1 point in 2007, and 11.7 ㎎/ℓat Yeongwol 1 point in 2011.

The BOD in Pyoungchang River basin was 0.8 ㎎/ℓ at Pyoungchang River 1 point in 2003, 0.7 ㎎/ℓat Pyoungchang River 1 point in 2007, 1 ㎎/ℓat Pyoungchang River 1 point in 2011, 1 ㎎/ℓat Pyoungchang River 2 point in 2003, 0.8 ㎎/ℓat Pyoungchang River 2 point in 2007, 1 ㎎/ℓat Pyoungchang River 2 point in 2011, 1 ㎎/ℓat Pyoungchang River 3 point in 2003, 0.8 ㎎/ℓat Pyoungchang River 3 point in 2007, and 0.8 ㎎/ℓat Pyoungchang River 3 point in 2011.

The DO was 11.4 ㎎/ℓat Pyoungchang River 1 point in 2003, 10.6 ㎎/ℓ at Pyoungchang River 1 point in 2007, 11 ㎎/ℓat Pyoungchang River 1 point in 2011, 10.5 ㎎/ℓat Pyoungchang River 2 point in 2003, 10.3 ㎎/ℓat Pyoungchang River 2 point in 2007, 10.6 ㎎/ℓat Pyoungchang River 2 point in 2011, 10.6 ㎎/ℓat Pyoungchang River 3 point in 2003, 10.6 ㎎/ℓat Pyoungchang River 3 point in 2007, and 10.8 ㎎/ℓat Pyoungchang River 3 point in 2011. The BOD and DO of river water quality in 2011 for three points of Pyoungchang River basin presented ‘very good’ applying to environmental standard for water quality.

The BOD in Chung-ju dam basin presents 0.8 ㎎/ℓat Yeongwol 2 point in 2003, 0.8 ㎎/ℓat Yeongwol 2 point in 2007, 0.6 ㎎/ℓat Yeongwol 2 point in 2011, 0.9 ㎎/ℓat Gagok point in 2003, 0.9 ㎎/ℓat Gagok point in 2007, 0.7 ㎎/ℓat Gagok point in 2011, 0.8 ㎎/ℓat Deokcheon point in 2003, 0.9 ㎎/ℓat Deokcheon point in 2007, 0.6 ㎎/ℓat Deokcheon point in 2011, 0.9 ㎎/ℓat Chung-ju dam point in 2003, 0.7 ㎎/ℓat Chung-ju dam point in 2007, 0.5 ㎎/ℓat Chung-ju dam point in 2011, 1㎎/ℓat Chung-ju point in 2003, 0.5 ㎎/ℓat Chung-ju point in 2007, and 0.4 ㎎/ℓat Chung-ju point in 2011.

The DO was 10.5 ㎎/ℓat Yeongwol 2 point in 2003, 10.7 ㎎/ℓat Yeongwol 2 point in 2007, 12.3 ㎎/ℓat Yeongwol 2 point in 2011, 10.6 ㎎/ℓat Gagok point in 2003, 10.3 ㎎/ℓat Gagok point in 2007, 11.8 ㎎/ℓat Gagok point in 2011, 10.5 ㎎/ℓat Deokcheon point in 2003, 10.2 ㎎/ℓat Deokcheon point in 2007, 12.3 ㎎/ℓat Deokcheon point in 2013, 9.7 ㎎/ℓat Chung-ju dam point in 2003, 8.5 ㎎/ℓat Chung-ju dam point in 2007, 10.3 ㎎/ℓat Chung-ju dam point in 2011, 10.4 ㎎/ℓat Chung-ju point in 2003, 9.9 ㎎/ℓat Chung-ju point in 2007, and 10.6 ㎎/ℓat Chung-ju point in 2011.

The BOD and DO of river water quality in 2011 for five points of Chung-ju dam basin presented ‘very good’ applying to environmental standard for water quality.

3. Result and Consideration

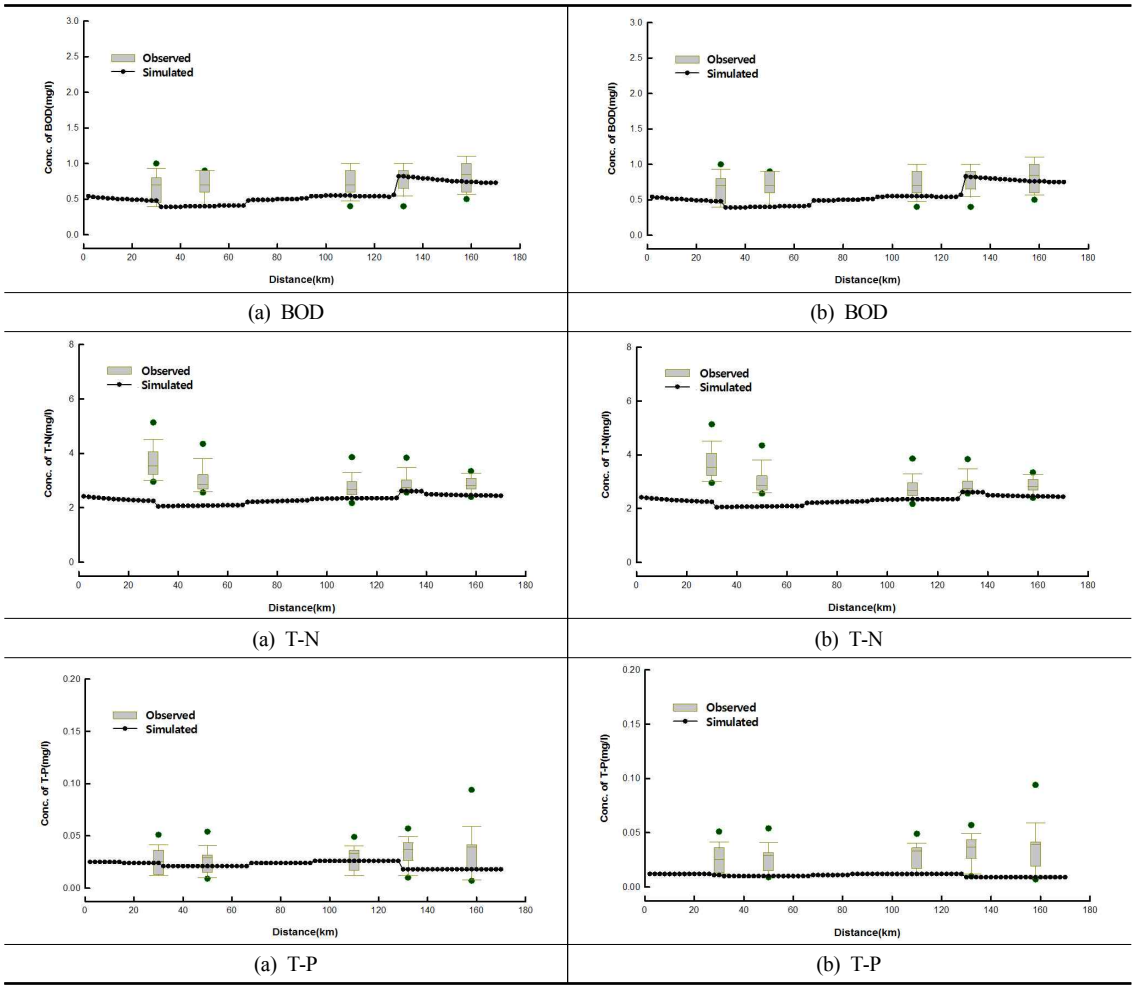
3.1 Calibration and Verification of the Model

Calibration means that it makes model value approach to measured value. It is the process of reducing the differences between model value and measured value by changing parameters of the model.

This research conducted the method of trial and error many times. It used the data on the rate of flow and water quality in March~April(calibration of the model) and October~November(verification of the model) that have less of a change in rate of flow on basis of 2009 for calibration and verification of the model.

Table 3. Discharge coefficient applied to QUAL2E

Reach Number	Element	related coefficient				Manning coefficient
		a	b	α	β	
Reach1	15	0.1804	0.2983	0.2095	0.4189	0.033
Reach2	18	0.1804	0.2983	0.2095	0.1160	0.033
Reach3	20	0.1804	0.2983	0.2095	0.1160	0.033
Reach4	11	0.1804	0.2983	0.2095	0.1160	0.033
Reach5	5	0.1804	0.2983	0.2095	0.1160	0.033
Reach6	8	0.0655	0.4454	0.2799	0.4134	0.033
Reach7	8	0.0655	0.4454	0.2799	0.4134	0.033



(a) BOD (b) BOD

(a) T-N (b) T-N

(a) T-P (b) T-P

Fig. 4. calibration(a) and verification(b) of QUAL2E water quality model

Table 4. Parameter values estimated by QUAL2E

Item	Parameter	Reach Number						
		1	2	3	4	5	6	7
BOD DO	K1	0.055	0.121	0.208	0.072	0.367	0.042	0.635
	K3	0.173	0.057	0.002	0.047	0.020	0.130	0.063
	K4	0.090	1.093	2.762	0.013	2.690	0.375	3.691

Table 5. Prediction of produced and effluent loadings in Chungju dam (2015)

(unit : kg/day)

watershed	Produced loading(2015)			Effluent loading(2015)[1]			Effluent loading(2015)[2]		
	BOD	T-N	T-P	BOD	T-N	T-P	BOD	T-N	T-P
Chungju dam	144,871.7	49,911.3	8,923.4	20,521.5	13,571.5	1,640.2	8,467.1	10,240.2	1,189.4
Namhan river	25,712.7	13,192.0	1,719.5	5,952.7	3,945.8	336.5	3,310.4	3,032.9	232.7
Inbukcheon	6,651.7	4,336.2	499.1	1,402.1	1,222.2	94.9	944.8	1,007.2	72.4
Soyang river	4,094.8	2,329.2	280.4	934.6	684.6	57.5	895.7	608.2	50.5
Uiam dam	14,966.2	6,526.6	940.0	3,616.0	2,039.0	184.2	1,469.9	1,417.6	109.8
Pyungchang river	56,278.5	18,115.2	3,988.8	6,472.2	4,084.7	639.0	1,260.8	2,878.0	450.1
Jucheon river	22,948.6	7,027.1	1,533.1	2,285.8	1,438.8	153.1	307.9	938.9	98.1
Pyungchang river	33,329.9	11,088.1	2,455.7	4,186.4	2,645.9	485.9	952.9	1,939.1	352.0
Chungju dam	62,880.4	18,604.1	3,215.1	8,096.6	5,541.1	664.7	3,896.0	4,329.2	506.6
Okdongcheon	4,280.1	2,196.3	286.0	633.6	555.6	44.3	201.4	302.9	24.7
Chungju lake	54,342.0	15,218.2	2,621.4	6,023.6	4,004.9	350.8	2,292.8	3,108.6	229.7
Dalcheon	4,258.2	1,189.6	307.7	1,439.4	980.6	269.6	1,401.8	917.7	252.3

1) excluding the environmental facilities
2) including the environmental facilities

3.2 Result of simulating water quality

The research implemented the model establishing virtual scenario according to existence of environment basic facilities for predicting the effect of water quality improvement by the reduction of contamination source and the installation of environment basic facilities in upper stream basin of Chung-ju dam.

The total BOD discharge load in Chung-ju dam basin was calculated as being reducing from 21,475kg/day in 2009 to 20,521kg/day in 2015 by the result of predicting contamination source occurrence and discharge load. The total BOD discharge load in 2015 was calculated as 8,467kg/day in case of establishing environment basic facilities in 2015.

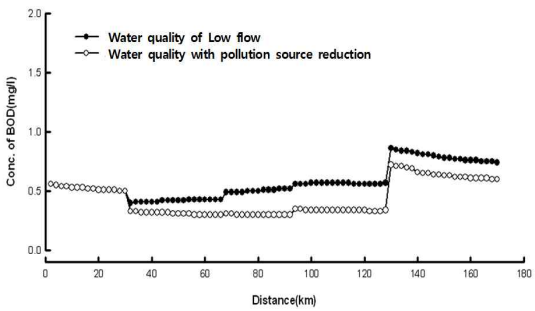


Fig. 5. Simulation result from the pollution source reduction based on the low flow(2015, BOD)

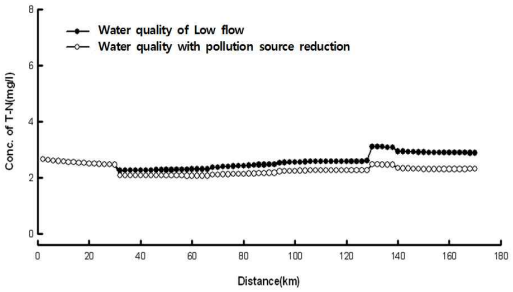


Fig. 6. Simulation result from the pollution source reduction based on the low flow(2015, T-N)

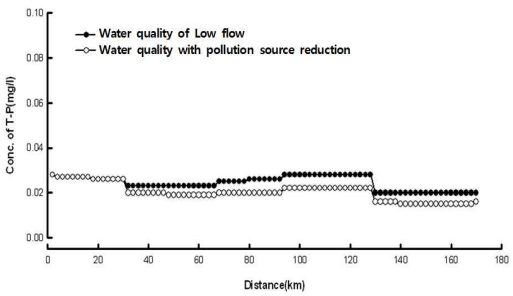


Fig. 7. Simulation result from the pollution source reduction based on the low flow(2015, T-P)

4. Conclusion

This research calculated occurrence load and discharge load in upper stream basin of Chung-ju dam for simulating upper stream water quality of Chung-ju dam, and the results of water quality modeling using QUAL2E model are as in the following.

1. The present condition of water quality in the basin presented that the BOD was 0.4 ㎎/ℓ～0.6 ㎎/ℓat upper stream basin of Nam Han River, 0.4 ㎎/ℓ～0.7 ㎎/ℓat Chung Ju Dam basin, and the DO was 11.4 ㎎/ℓ～12.3 ㎎/ℓat upper stream basin of Nam Han River , 0.6 ㎎/ℓ～11 ㎎/ℓat Pyoungchang River basin, 10.3 ㎎/ℓ～12.3 ㎎/ℓ at Chung Ju Dam basin. The BOD and DO of river water quality in 2011 for the total basin presented ‘very good’ applying to environmental standard for water quality.
2. The total BOD discharge load in Chung-ju dam basin was calculated as being reducing from 21,475kg/day in 2009 to 20,521kg/day in 2015 ,and the total BOD discharge load in 2015 was calculated as 8,467kg/day in case of establishing environment basic facilities in 2015.
3. Pollution load in upper stream basin of Chung-ju dam presented that contamination source is gradually getting a decrease trend. The effect of about 23% water quality improvement on T-N and T-P was predicted according to establishing environment basic facilities in 2015.

It is recommended that predictions of water quality considering regulations and policy measures for water quality improvement in upper stream basin of Chung-ju dam on basis of the results of this research. would be needed. Additional researches with consideration for management plans of water quality by contamination sources of upper stream basin for Chung-ju dam, introduction of advanced wastewater treatment facilities by massive environment basic facilities at the regions highly having discharge load by contamination sources, and point pollution improvement facilities would be needed.

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