Analysis of Korean TMLD Design Flow Variation due to Large Dam Effluents and Water Use Scenarios

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ABSTRACT: The goal of this study is to establish an integrated watershed hydrologic model for the whole Nakdong River basin whose area is an approximately 24,000 km2. Including a number of watershed elements such as rainfall, runoff, water use, and so on, the proposed model is based on SWAT model, and is used to improve the flow duration curve estimation of ungauged watersheds for Korean Total Maximum Daily Load (TMDL). The model is also used to recognize quantitatively the river flow variation due to water use elements and large dam effluents in the whole watershed. The established combined watershed hydrologic model, SWAT-Nakdong, is used to evaluate the quantified influences of artificial water balance elements, such as a dam and water use in the watershed. We apply two water balance scenarios in this study: the dam scenario considering effluent conditions of 4 large multi-purpose dams, Andong dam, Imha dam, Namgang dam, and Habcheon dam, and the water use scenario considering a water use for stream line and the effluent from a treatment plant. The two scenarios are used to investigate the impacts on TMDL design flow and flow duration of particular locations in Nakdong River main stream. The results from this study will provide the basic guideline for the natural flow restoration in Nakdong River.

1 INTRODUCTION

The long-term stream flow data is the most important data for watershed management such as irrigation, flood control, river environmental management, land use, and agriculture management. Especially, the Total Maximum Daily Load (TMDL) process which have taken effect in Korea since 2005 needs to such a data with temporally daily based resolution and spatially more than 1 gauging station per 500 km2 . However, in the case of Korea, since stream flow has been observed mainly for flood control, the observed data exists on the main stream of large river with hourly resolution in temporal scale. Therefore, there are a number of ungauged basins in middle-sized streams and tributaries, so that such a lack of data is blocking process in the Korean TMDL. The flow duration curve estimation for such ungauged watersheds is classified into two categories: empirical methods using rainfall data and watershed characteristics, and simulation methods using hydrologic models. In Korea, the specific discharge method has been mainly used since this method only needs rainfall data and watershed area. However, the specific discharge method to estimate flow duration curve of ungauged basins cannot consider various effect of land use, soil characteristics, and flow control elements such as water intake and treatment or dam effluents. It is essential to study quantitatively for the effects of river flow variations in downstream due to the upstream dam effluent and the water usage amounts from stream line and watershed in the aspect of water resources and river environment management policy such as TMDL. Therefore, this study primarily focuses on establishing the integrated watershed hydrologic model for the whole Nakdong River watershed, so called SWAT-Nakdong model, which can evaluate the integrated effects due to the changes of water balance elements such as dam effluents and spatiotemporal distribution of rainfall in the watershed, water usage amounts in stream line, the effluents from treatment plants, and water transfer between watersheds, and producing the long-term data of river flow to construct the flow duration curve at each unit subbasin for Korean TMDL. Using the SWAT-Nakdong model, the attempt to quantify the effect of the dam and water usage on the flow duration curve, especially on TMDL design flow is made. In order to simulate the stream flow at each unit subbasin, the watershed areal mean precipitation should be firstly estimated. For this estimation, arithmetic mean method, thiessen method, and isohyetal method have been used, but those are for converting point precipitation into areal one, thus cannot fully represent the spatial inhomogeneity of precipitation. Accordingly, the Kriging method which is known to reflect the spatiotemporal patterns of rainfall better than others is applied to estimate each unit subbasin mean areal precipitation. The water balance scenarios are also developed and applied in order to quantify the influence of river flow variations based on them. The scenarios are divided into the dam scenarios with the effluent condition of the large multi-purpose dams (Andong dam, Imha dam, Namgang dam, and Habcheon dam) and the water use scenarios with the water usage amounts from stream line, effluent volume from treatment plants, and water transfer between watersheds. Natural flow duration curves excluding artificial elements are finally estimated so that it becomes standard for the analysis of artificial river flow variations.

2 RESEARCH STRUCTURE

Since there are 4 large multi-purpose dams in upstream and midstream of Nakdong River basin, the flow in dry period is controlled in a great deal. The elements of water usage amounts and sewer treatment effluents generated from a third-biggest city in Korea living about 2,500,000 people in the midstream largely distort the flow duration curve in Nakdong River. Moreover, the water usage from an about 40,000,000 people-living city, which is the second biggest city in Korea, in the downstream changes the river flow of Nakdong River quite differently from that of its natural condition. Fig. 1 represents the research procedure used in this study. Firstly, massive data for basic GIS data, rainfall data, observed runoff data, meteorological data, water usage and treatment plant effluents data for stream line and watershed, and dam effluents data is collected. Based on available rainfall gauging stations, daily areal mean precipitation at each unit subbasin is estimated using universal Kriging method with complementing missing data. Then, through the calibration and verification processes on the established WAAT-Nakdong model with observed rainfall-runoff data, daily river flow data from 34 sub-basins in the whole Nakdong River watershed is produced. Flow variations due to the each water balance scenario are also analyzed.

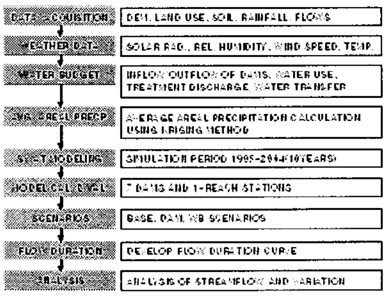


Fig. 1. Flow chart of procedures and methods used in this study

Table 1. Modeling Scenarios

SCENARIO		Water Balance Elements Considered
BASE		No Dams & No Water-uses
DAM	A	Andong Dam
	I	Imha Dam
	AI	Andong & Imha Dam
	H	Habcheon Dam
	N	Namgang Dam
	HN	Habcheon & Namgang Dam
	ALL	4 Dams all considered
WB		Water usage & Treatment discharges

Table 1 shows the simulation scenarios developed and applied in this study in order to evaluate river flow variations with dam effluents and water usages. The scenarios can be divided into 3 classes. The first, basic scenario (the name "BASE" in Table 1) is regarded as so called natural flow condition which is simulated by executing the SWAT-Nakdong model without considering anthropogenic flow disturbances such as dam effluents, water intakes and treatment plant effluents. The second, dam scenarios are classified into 3 categories: 1) based on BASE scenario, the case considering only effects of each effluent from Andong dam (A), Imha dam

(I), Namgang dam (N), and Habcheon dam (H), 2) based on BASE scenario, the case identifying flow variations in particular Nakdong main streams with upstream A+I and midstream H+N, and 3) based on BASE scenario, the case including all dams' effect. The third, in the water usage scenario (WB) the effect of water intakes and treatment plant effluents is considered in addition to the BASE scenario.

3 SWAT-NAKDONG MODEL

The interested watershed in this study is Nakdong River basin, the longest river in south Korea, with the area of 23,790km2 (25.9% of south Korea) and the length of 510.36 km. The whole watershed are divided into 34 unit subbasins: 7 dams of Andong dam, Imha dam, Habcheon dam, Namgang dam, Unmun dam, Milyang dam, and Youngcheon dam, and the first tributaries and principal points in the main stream of Nakdong River (Fig 2). Based on the total 34 unit subbasins, 174 hydrologic response units (HRUs) are generated with land use map 10% and soil map 10%. The SWAT-Nakdong model is simulated for 11 years (1994 ~ 2004), and the first year is excluded from analysis for the purpose of the stability of long-term hydrologic simulation. The model parameter estimation procedure consists of two steps: 1) model parameters are roughly estimated using daily dam release data of 7 main dams, and applied to nearby unit subbasins which have similar watershed characteristics. 2) Model parameters are finally determined using daily river flow data of Jindong station where highly reliable long data can be obtained. Jindong station is located in the unit subbasin ND_10 (see Fig. 2).

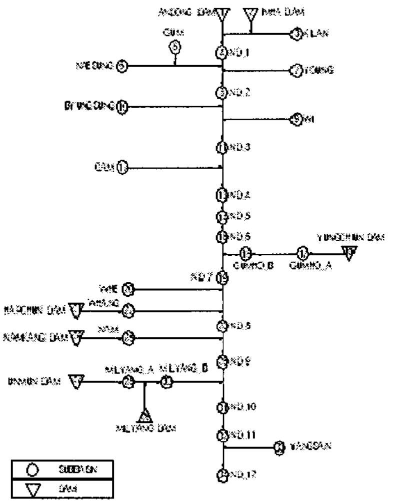
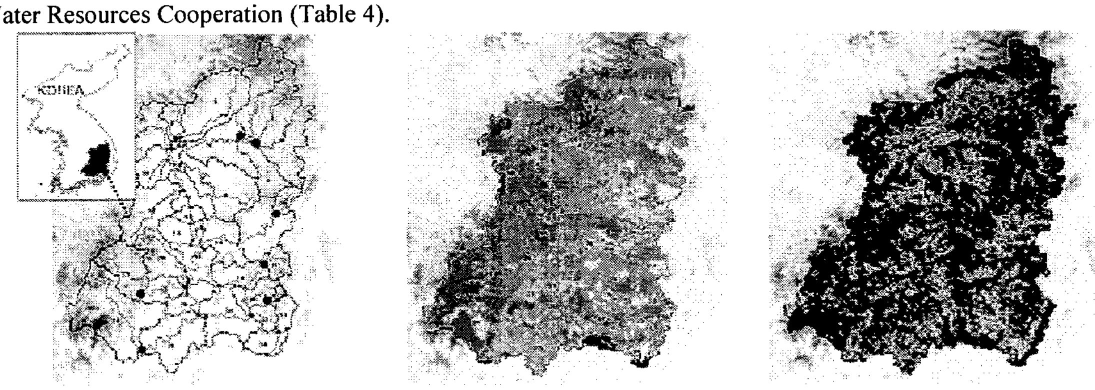


Fig. 2. Unit subbasin map of Nakdong river basin

Using SWAT-Nakdong model, it is quantified how much the river flow is altered due to dam effluents and water usage in Nakdong River basin. Especially, the quantification of the effect of dam and water use components on the Korean TMDL design flow, which is the 10-year-averaged low flow, is served as the basic investigation in order to evaluate the suitability of water use in stream line or the dam effluent control for securing the maintenance flow for the purpose of river environmental management. This model results are also used as the design flow for Korean TMDL itself.

3.1 Input Data

Traverse Mercator (TM) presented in Korean standard surveying method is chosen as the coordinates system for establishing the GIS-based SWAT model, and the Central origin point is set as the coordinate origin point. Contour lines for generating DEM are produced through vectorizing, giving altitude values in contour lines, making TIN model, and processing the production of GRID model after scanning 1:50,000 topographic maps which can be obtained Korea National Geographic Information Institute (Fig. 3(a)). The 1:50,000 soil maps which are obtained from Korean Plant Environmental Research Institute under Korean Rural Development Administration are used after being set to be identical to DEM's coordinates system, scanning and vectorizing soil map, giving attributes to soil maps, and producing GRID model (Fig. 3(b)). Land use maps are established and applied using soil coverage classification maps from Ministry of Environment (Fig. 3(c)). Establishing a regional hydrologic model requires to develop a rainfall analysis system including the selection of rainfall observation network and the estimation of areally averaged precipitation. The rainfall analysis system for Nakdong River basin developed in this study consists of the selection of rainfall observation network, the daily rainfall data collection in observation stations, the calibration and verification of daily rainfall data for each point using the point universal Kriging method, and the estimation of spatially averaged precipitation at each subbasin. The spatially averaged precipitation is estimated using the block universal Kriging method for the whole Nakdong River basin in order to perform thoroughly spatiotemporal rainfall analysis. Total 56 precipitation gauging stations including Sangbuk are selected, and daily mean rainfall is applied to simulate daily flow from the established hydrologic model. Table 2 shows the spatially averaged precipitation for 10 years for each of 34 unit subbasins. The meteorological data such as solar radiation, temperature, wind speed, and relative humidity are required to calculate evapotranspiration in SWAT-Nakdong model. Table 3 lists 21 weather stations including Habcheon. The intake water amounts for the domestic purpose at each unit subbasin, the effluents from sewer and industrial wastewater treatment plants, the intake water for agricultural and industrial usage with the consideration of their recovery rates, and the water transfer among subbasins including the Youngcheon's aqueduct are considered as water balance components. Measured daily inflow and outflow data in each dam are also collected, and the missing date is supplemented in order to apply to SWAT-Nakdong model. The actual physical characteristics of each dam, which is also required in our model system, can be obtained from Korea Water Resources Cooperation (Table 4).



(a) River network (b) Soil coverage (c) Land use coverage

Fig. 3. River network and soil and land use coverage

Table 2. Average areal precipitations (1995-2004)

NO.	prec.(㎜)	NO.	prec.(㎜)	NO.	prec.(㎜)	NO.	prec.(㎜)
1	1208.44	10	1236.32	19	1118.07	28	1165.40
2	1070.29	11	1154.72	20	1163.69	29	1320.10
3	1039.26	12	1159.72	21	1373.46	30	1261.25
4	1105.67	13	1121.32	22	1284.79	31	1305.60
5	1199.16	14	1112.49	23	1145.38	32	1337.76
6	1262.11	15	1112.89	24	1531.55	33	1422.62
7	1282.58	16	1090.99	25	1487.59	34	1528.65
8	1149.36	17	1118.00	26	1223.37		
9	1069.65	18	1151.65	27	1120.17		

Table 3. Weather stations

NO.	Name	NO.	Name	NO.	Name
1	habcheon	8	busan	15	weosung
2	gumi	9	sanchung	16	jinju
3	namhae	10	andong	17	chupung
4	daegu	11	youngduk	18	tongyoung
5	masan	12	youngju	19	pohang
6	mungyung	13	youngchun	20	geochang
7	milyang	14	ulsan	21	chunyang

Table 4. Physical characteristics of reservoirs

DAM	Emergency spillway surface area (ha)	Emergency spillway volume (m^3)	Principle spillway surface area (ha)	Principle spillway volume (m^3)	Initial reservoir volume (m^3)
ANDONG	5,800	135,800	5,150	124,800	124,800
IMHA	3,200	64,200	2,640	59,500	59,500
HAPCHUN	3,000	87,000	2,500	79,000	79,000
NAMKANG	4,200	40,000	2,820	30,920	30,920
MILYANG	220	7,360	208	6,980	6,980
YOUNGCHUN	690	9,640	582	8,140	8,140
UNMUN	783	13,534	730	12,617	12,617

3.2 Model Calibration

The SWAT model calibration is performed through fitting in order of daily river flow, peak flow, and recession curve, and is carried out from upstream to downstream. Among recent 10 years data, 1995 and 1996 are drought years, so that these years are excluded in calibration process since their low and extremely low flow data are thought not to be reliable. Accordingly, the daily inflow data into each dam from 1997 to 2004 are used to calibrate SWAT-Nakdong model. Table 5 shows the hydrologic components such as total rainfall, evapotranspiration, surface flow, lateral flow, and ground water flow, generated through the model calibration using inflow data into each dam. The model parameters estimated from dam site calibration are applied to nearby unit subbasins with the consideration of watershed characteristics. Jindong river stage station is set to be the model calibration standard point for stream line, and the model calibration is performed with the conversion from observed stage data to river discharge data using rating curve. Table 6 shows the calibration performance of SWAT-Nakdong model. The reliance of calibration results are represented by relative peak error (RPE), relative volume error (RVE), absolute mean bias (AMB), root mean square error (RMSE), and correlation coefficient (CC). Fig.4 compares the results of measured and simulated monthly stream flows at Andong dam and Jindong station. While the correlation coefficients of yearly and monthly flow at Andong dam, Imha dam, and Habcheon dam are favorable 0.84 ~ 0.97, the one of daily flow is 0.48 ~ 0.80. These differences are caused by the reason that the model parameter is estimated to make a good agreement to relatively lower flow data, so that daily flow data in flood season is overestimated. For practical purposes in Korean TMDL, better representation in low flow is more important than high flow representation. The verification error analysis is performed with the flow duration carves of measured data and simulated daily flow data of SWAT-Nakdong model. Based on the results, the range of coefficients is 0.59 ~ 0.91 in Andong dam, 0.76 ~ 0.82 in Imha dam, and 0.68 ~ 0.91 in Habcheon dam, which are favorable results. This result is thought to be caused by the calibration process performed with comparatively highly reliable dam inflow data. Note that a particular flow data over the flow duration curve is a flow data in a particular day among a number of daily flow data, so that this value is highly changeable. The result of verification error analysis in stream line shows that Jindong has a favorable 0.65 ~ 0.76 coefficient.

Table 5. Hydrologic components of dam subbasins

	Hyd. components	%	Yield(mm)		Hyd. components	%	Yield(mm)
AN DONG	Rainfall	100.00	1323.00	HAP CHUN	Rainfall	100.00	1492.00
	Evaporation	39.20	521.00		Evaporation	37.70	577.00
	Surface flow	20.30	270.00		Surface flow	23.40	358.00
	Lateral flow	17.70	235.00		Lateral flow	24.40	374.00
	Ground water flow	22.30	297.00		Ground water flow	11.90	183.00
IM HA	Rainfall	100.00	1134.00	NAM GANG	Rainfall	100.00	1635.50
	Evaporation	51.90	599.00		Evaporation	35.70	600.50
	Surface flow	4.20	48.00		Surface flow	34.20	576.00
	Lateral flow	11.70	135.00		Lateral flow	14.30	240.00
	Ground water flow	30.50	352.00		Ground water flow	13.00	219.00

Table 6. Statistical results for model calibration

		RPE	RVE	AMB	RMSE	CC			RPE	RVE	AMB	RMSE	CC
AN DONG	yearly	17.38	14.63	117.13	132.01	0.97	HAP CHUN	yearly	19.4	4.78	110.2	141.67	0.92
	monthly	22.01	14.64	13.96	21.23	0.93		monthly	34.04	4.68	7.1	13.98	0.93
	daily	66.22	14.58	25.95	96.6	0.59		daily	21.11	4.7	11.23	43.04	0.8
	Q95	41.84	40.27	11.32	13.61	0.91		Q95	17.21	0.49	2.82	3.52	0.91
	Q185	56.93	25	3.58	4.84	0.94		Q185	1.21	8.63	1.17	1.47	0.94
	Q275	2.26	10.28	1.61	1.76	0.68		Q275	0.44	13.14	1.12	1.23	0.83
	Q355	43.5	44.18	0.48	0.78	0.59		Q355	8.11	14.49	0.85	1.02	0.68
IMHA	yearly	38.39	21.67	134.32	194.25	0.96	JIN DONG	yearly	16.48	12.78	91.03	121.73	0.78
	monthly	53.35	21.71	15.34	25.54	0.84		monthly	37.31	12.78	162.2	288.51	0.84
	daily	83.49	21.63	25.35	93.04	0.48		daily	61.31	12.83	222.66	617.44	0.7
	Q95	31.5	107.05	14.74	17.08	0.82		Q95	14.27	13.67	121.39	160.02	0.76
	Q185	23.4	33.77	2.08	2.97	0.91		Q185	16.91	15.98	53.63	63.42	0.77
	Q275	9.15	21.65	0.69	1	0.75		Q275	5.27	3.75	47.33	52.71	0.45
	Q355	33	13.62	0.23	0.27	0.76		Q355	69.79	3.56	28.97	35.03	0.65

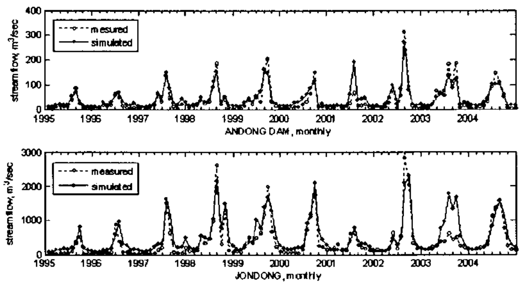


Fig. 4. Time series plot of measured and simulated monthly stream flows

4 RESULTS

4.1 River Flow Variation in each scenario

Table 7 shows the comparison results between the BASE scenario which is regarded as the natural flow condition and each one of 3 dam scenarios: the case of considering each of Andong dam (A), Imha dam (I), Namgang dam (N), and Habcheon dam (H), the case for Andong - Imha dam (AI) and Namgang - Habcheon dam (NH), and the case for all dams (ALL). It can be concluded that the effect of dam effluents on the downstream flow decreases as flow volume increases from extremely low flow to mean flow, and that the effect caused by dam effluents is reduced as flow reaches towards downstream. In addition, comparing the BASE scenario, the cases of considering separately Andong dam (A), Imha dam (I), Namgang dam (N), and Habcheon dam (H) shows that the low flow in downstream Jindong river stage station is increased with 32.92%, 8.73%, 15.43%, and 13.19%, respectively. When Andong - Imha dam (AI) and Namgang - Habcheon dam (NH) are combined, respectively, the low flow is increased with 45.66% and 26.87%. When considering all dams, in the Jindong station, the extremely low flow, low flow, and mean flow are increased by 124. 78%, 168.58%, and 316.98%, respectively, compared with corresponding BASE flows. This means that the dam effluents are dominant in case of extremely low flow and low flow. Fig 5 illustrates the variations of stream flow in each dam scenario and each flow in ND7, ND8, ND9, and ND12. The result of water usage scenario for flow duration curve is expressed in Table 8 and Fig 6. It is concluded that the stream flow variations due to water usage change slightly as flow volume increases and change greatly as volume decreases. In terms of flow variation in stream line stations, Q185, Q275, and Q355 are reduced in ND1~ND7, and all of them are increased in ND7~ND10 because of large river water intake before Daegu city, which is the third-largest city in Korea, and effluents from treatment plants in Daegu and other downstream cities in mid-Nakdong River, which causes extremely low flow to be increased due to annually constant discharge. The flows in ND11~ND12 are shrunk because of intake for mainly domestic water usage from Busan which is the second-biggest city in Korea. Fig.7 demonstrates the daily mean stream flows at ND9 station in the scenarios BASE, ALL, and WB. Fig.8 describes the comparisons of daily stream flows for 3 scenarios at ND9 station. Fig.9 shows the flow duration curve to compare the effect of dam effluents and water usage with natural flow in ND6 and ND7 of midstream of Nakdong River. ND6 and ND7 are located in the immediate up and down stations of Daegu which has a big influence in the Nakdong river mainstream flow variation due to a lot of water usage. Fig. 9 also represents the flow duration curve in ND10 and ND11 where there are the water intake points for Busan and Ulsan cities. Busan is the second-biggest city in Korea and Ulsan is one of five biggest cities in Korea. In all stations, the flow variations caused by dam effluents and water usage changes rapidly as flow volume deceases. The distorted flow for extremely low and low flow periods are bigger than natural flow with the effect of constant treatment plant discharge in all stations except that in ND6 station, the extremely low and low flow decrease rapidly compared with BASE flow condition because of the intake water from Daegu. In ND11 station, the flow becomes similar to BASE flow since Busan and Ulsan release water to Nakdong River after taking it. It is also shown that dam effluents make the flow duration curve to be distributed uniformly especially in extremely low flow and low flow periods. Fig.10 describes the comparison of monthly stream flows with natural flows in ND6, ND7, and ND11.

Table 7. Variations of the stream flows (dam scenarios) (scenario / BASE, %)

	STATION	ALL	A	I	AI	H	N	HN
Q185	ND_7	122.83	109.26	119.30	122.83	100.00	100.00	100.00
	ND_8	125.39	108.13	114.82	119.66	105.60	100.00	105.60
	ND_9	124.78	107.10	110.29	116.93	104.81	105.67	110.48
	ND_12	122.64	104.41	107.58	111.65	104.04	103.66	107.81
Q275	ND_7	181.86	156.59	116.59	181.86	100.00	100.00	100.00
	ND_8	181.30	143.68	111.04	162.27	118.83	100.00	118.83
	ND_9	168.58	132.92	108.73	145.66	115.43	113.19	126.87
	ND_12	162.73	126.26	109.07	138.69	111.92	111.49	121.21
Q355	ND_7	371.41	285.88	170.23	371.41	100.00	100.00	100.00
	ND_8	359.69	229.41	147.14	286.66	183.10	100.00	183.10
	ND_9	316.98	187.77	131.49	223.54	154.71	150.40	199.67
	ND_12	303.12	170.49	122.72	198.22	145.27	140.98	181.48

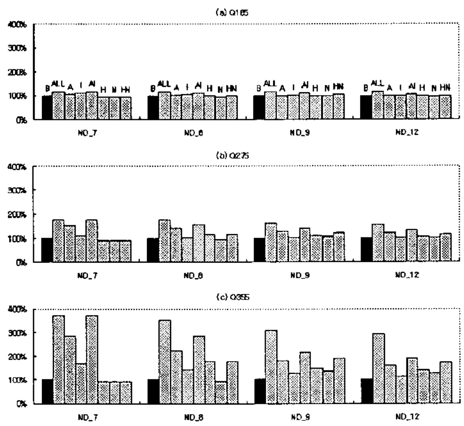


Fig. 5. Variations of the stream flows at ND7, ND8, ND9, ND12 (scenario/BASE, %)

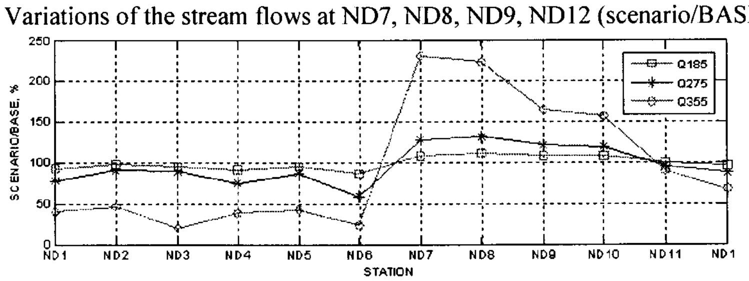


Fig. 6. Comparisons of the flow statistics (1995-2004) at each subbasin (WB scenario)

Table 8. Variations of the stream flows (WB scenario) (scenario / BASE, %)

STATION	Q185	Q275	Q355
ND_1	92.53	77.83	39.26
ND_2	96.98	89.63	46.16
ND_3	95.37	89.07	19.18
ND_4	91.27	74.68	37.96
ND_5	95.42	85.79	42.18
ND_6	86.26	57.97	23.52
ND_7	107.79	128.04	230.53
ND_8	110.63	131.70	223.50
ND_9	107.92	121.78	164.42
ND_10	107.40	118.46	156.23
ND_11	98.84	94.26	88.79
ND_12	96.40	87.06	67.07

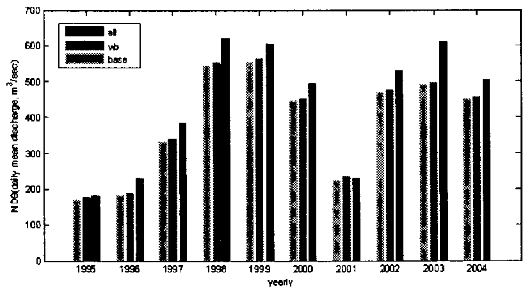


Fig. 7. Daily mean stream flows (1995-2004) at ND9 station

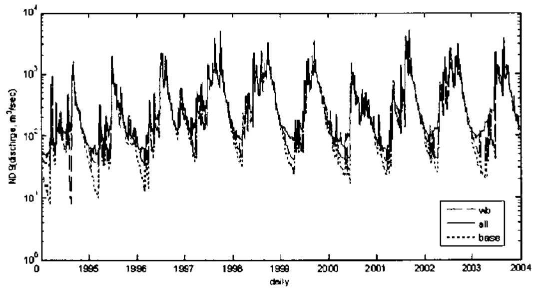


Fig. 8. Comparisons of the daily stream flows (1995-2004) at ND9 station

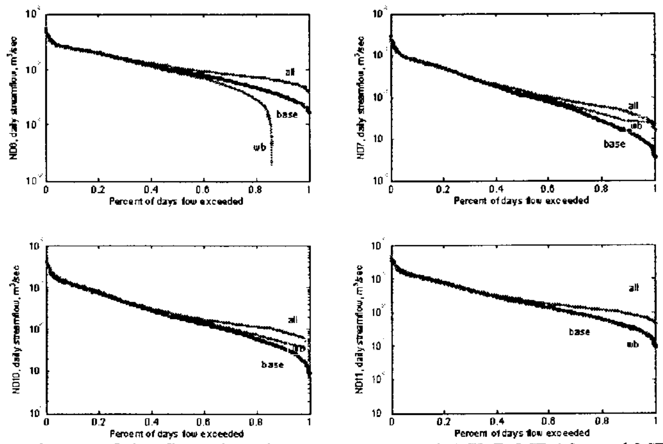


Fig. 9. Comparisons of the flow duration curve at ND6, ND7, ND10, and ND11 stations

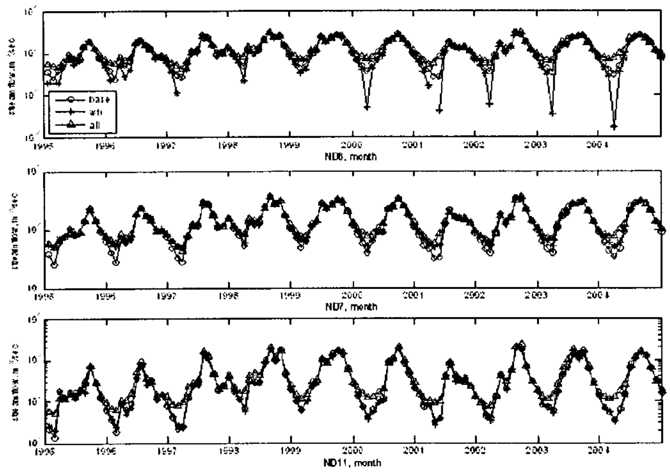


Fig. 10. Comparison of the monthly stream flows at ND6, ND7, and ND11 stations

4.2 Effect on TMDL Flow

The design flow for Korean TMDL is 10-year-averaged low flow, and pollutant loads are allocated for unit subbasin and local governments to apply as a standard for local development and conservation. It is necessary to understand the effect of dam and water use components on TMDL design flow and to evaluate the suitability of water use in stream line and the dam effluent control to maintain water quantity level required for future river environment management. ND1 station has a direct influence of Andong and Imha dam effluents. Its flow is reduced to 7.416 m^3/sec from natural condition 9.528 m^3/sec because of water usage, but is increased again to 28.763 m^3/sec and 14.474 m^3/sec because of Andong dam (A) and Imha dam (I) effluent, respectively. The design flow becomes 36.582 m^3/sec because of the effluents effect from 2 dams. ND6 station undergoes the flow reduction of approximately 13.60 m^3/sec due to water usage from Daegu. ND7 has the flow increase of about 11 m^3/sec and 32 m^3/sec because of the effluents from treatment plants and the upstream dam effluents, respectively. ND11 and ND12 show the flow reduction due to domestic and industrial water usage (see Fig. 11). It is confirmed that stations are vastly affected by effluents from treatment plants, water usage in stream line and watershed, and dam effluents especially in extremely low flow and low flow periods. However, the TMDL-Nakdong river design flow estimated and applied with specific flow estimation method using area and rainfall ratio in current Jindong river stage stations cannot reflect these effects of dam and water usage. Therefore, it is essential to quantitatively consider the effect of dam and water usage and to estimate TMDL design flow from such considerations.

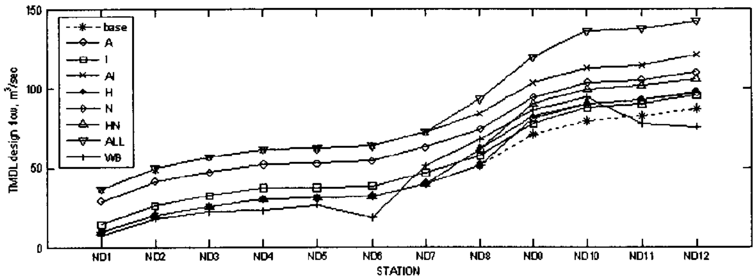


Fig. 11. Comparison of TMDL design flows for each scenario

5 CONCLUSIONS

This study tries to give a direction for decision making for watershed management – water resources, river environment, soil, land, and agriculture management – with simulating long- term hydrologic cycle process in a large watershed. The integrated watershed hydrologic model, SWAT-Nakdong, is established to consider rainfall, runoff, and water balance components. Daily based long-term flow data, an essential hydrologic component, are established, and river flow variations are quantitatively analyzed with water distorted scenarios (dam effluents and water usage scenarios) that have a direct influence on river flow variations. The summary of this study is the following; 1) the integrated watershed hydrologic model, SWAT-Nakdong, for the whole Nakdong River watershed is established, and its calibration and verification process using actual data are performed. 2) Through various scenario simulations, the flow variations caused by upstream dam effluents and water usage in main Nakdong River points, and the TMDL design flow changes are quantitatively analyzed.

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