Lowflow Analysis of Nakdong River Basin by SSARR-8 Model

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Abstract: The SSARR model adopting IS(integrated snowband) watershed model is applied to Nakdong River basin for lowflow analysis. The IS watershed model is added to new version of the SSARR which has functions of simulating evapotranspiration, infiltration and lower zone routing. It provides annual water budget informations as an output file and can be operated by interactive mode. Sensitivity analysis for both cases of high and lowflows was carried out, which becomes the knowledge base for model calibration. Model verification was performed using the relative errors of highflows and absolute errors of lowflows at the control points. Monthly water budget analysis was done by IS watershed model, and it reveals that runoff coefficient is 52.6%.

1. Introduction

Tank model(Sugawara et al., 1984) was widely used as a watershed model because it was developed in Japan whose watershed conditions are similar to that of Korea(Park, 1993). But this model is hard to modify because it is a kind of black box model. Recently attempts have been made to test the applicability of SSARR(Streamflow Synthesis and Reservoir Regulation) or NWSRFS(National Weather Service River Forecast System) model which has a function of reservoir operation and includes physical mechanics of soil moisture. NWSRFS model is generally applied to hydrologic forecasting in a flood season because of a limitation in modeling time step. In Korea, this model was only applied to a flood simulation (Cho et al., 1995). In this research, SSARR model was selected as the best model for lowflow analysis model of the Nakdong River basin considering meteorological, geological characteristics and amounts of observation data. Since SSARR model had been developed by Corp of Engineers in 1956, it has been widely used model for the purpose of reservoir controlling and analysis of real time daily runoff for large watershed. This model has been equipped with basic framework for a watershed and channel routing in 1975(SSARR-4), and Integrated Snowband(IS) watershed model and operational forecasting function were added later(SSARR-8). This model, which includes modules of reservoir regulation as well as watershed analysis and channel routing, has

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been successfully applied to large rivers such as Columbia river(Rockwood, 1961) in America, and Mekong river(Rockwood, 1968) in Vietnam, and domestically, Kang(1986) applied it to the Han River basin, An and Lee(1989) to the Bochung River of Keum River basin, and KOWACO(1989) to Nakdong River basin respectively. SSARR model, which can simulate runoff not only from rainfall but also from snowfall, is lumped parameter model and its optimal values of at least more than 24 parameters are determined by trial and error method. This model can select an interval of modeling time from 6 minutes to 24 hours, and according to Nemec's classification of hydrologic forecasting(1986), it can be classified as index use model among conceptual soil moisture calculation models, where some parameters such as SMI(soil moisture index), ETI(evapotranspiration index), and BII(baseflow infiltration index) are given as indices.

2. IS Watershed Model

Until recently, SSARR model applied domestically is the SSARR-4 developed before 1975 which adopts DC(depletion curve) watershed model. SSARR-8 model developed Recently contains DC watershed model and IS watershed model making it possible to choose two models. Although the main emphasis in its development was snow simulation in mountainous areas, this model includes all the features of the DC model for rain-only simulation. This model is most valuable in long-term simulations. It has a function of analysis of interception, a more flexible evapotranspiration simulation, and simulation of long-term return flow from groundwater. This model can tabulate the result of annual water budget analysis for each sub-basins.

IS watershed model permits flexible subdivision of the basin into from 1 to 20 bands and is designed to simulate the snowpack and soil moisture condition of a drainage as they vary with elevation. For the simulation of a rain-only basin, the variation of precipitation and soil moisture with elevation and of evapotranspiration with temperature can also be modeled with this technique. The input stream can be the form of free-format, and all place names including basin names can be inputted as a form of characters as well as numbers. In this research, we carried out the lowflow analysis of Nakdong River basin fully utilizing the function of IS watershed model of SSARR.

The basic routing method used in the watershed and channel routing models is a 'cascade of reservoir' techniques, wherein the lag and attenuation of the flood wave are simulated through successive increments of lake-type storage. Continuity(Eq. 1) and storage equation(Eq. 2) are used in routing of reservoir.

$$I_t = O_t + \frac{dS_t}{dt} \tag{1}$$

$$S_t = T_s O_t \tag{2}$$

where I_t and O_t are inflow and outflow of the computational period t. S_t is storage, T_s is time of storage. Eq. (1) is expanded into Eq. (3), and by substituting Eq. (2) into it, Eq. (4) may be derived.

$$[(I_1+I_2)/2-(O_1+O_2)/2]\Delta t = S_2-S_1 \tag{3}$$

$$O_2 = O_1 + \Delta t(I_m-O_1)/(T_s+\Delta t/2) \tag{4}$$

where subscript 1 and 2 denote the beginning and end of computational period, I_m is mean inflow, and Δt is time interval.

Parameters required for watershed, channel, and reservoir routing are the number of

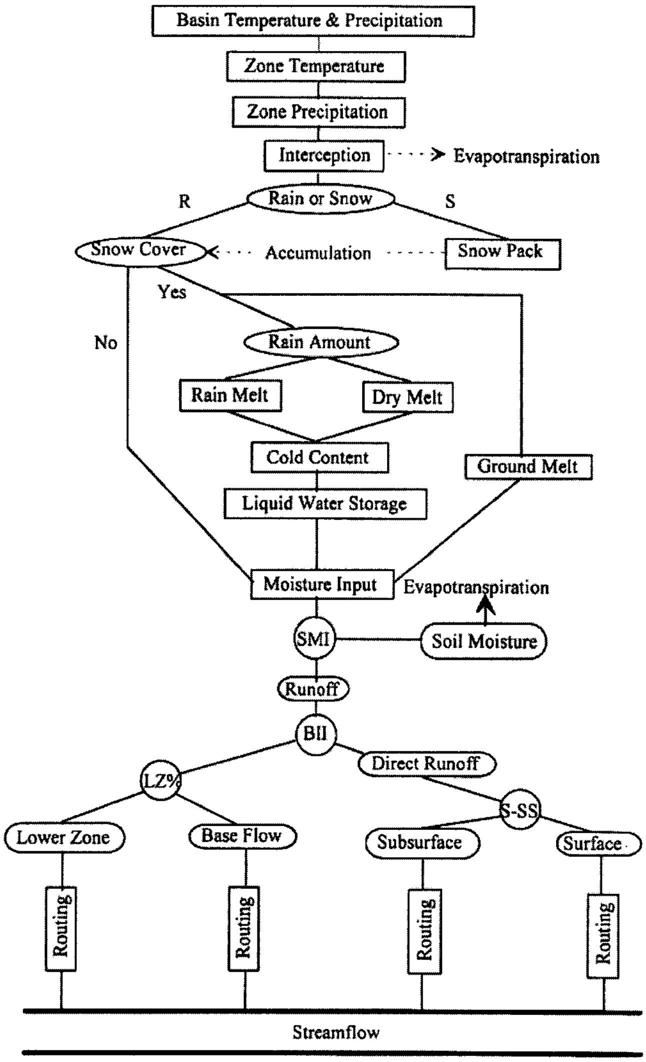

Fig. 1. SSARR 'Snowband' Watershed Model

imaginary reservoirs and storage time of each reservoir. Time of storage is directly inputted to the watershed model, but it is a function of flowrate in channel routing model(Eq. 5). We can see that from Eq. (2), channel routing and reservoir model are nonlinear while watershed model is linear.

$$T_s = \frac{KTS}{I^n} \tag{5}$$

where KTS is constant determined by trial and error method, I is inflow, n is a coefficient usually between -1 and 1. A flow chart for watershed model is shown in Fig. 1. First, the rainfall and temperature values for each band from observed data are to be calculated. Separation of rainfall and snowfall except for the loss of interception for each band and summarizing of the snowmelt for each sub-basin are needed. This moisture input runoffs according to SMI(soil moisture index) and increases the soil moisture or loses it by evapotranspiration.

Runoff is first divided into a direct component and a baseflow component by BII(baseflow infiltration index). Direct runoff is divided into surface runoff and subsurface runoff by S-SS(surface-subsurface), and baseflow is divided into baseflow and lower zone by LZ(lower zone). The results are summarized to arrive at channel inflow of surface, subsurface, baseflow, and lower zone by the routing method explained above.

3. Determination of Input Data

3.1 Reference Parameters

Parameters and reference values must be determined before performing a sensitivity analysis. Parameters of a hydrologic model are divided into physical parameters, hydrometeorologic parameters, process parameters(Fleming, 1977). Parameters required to run SSARR model are selected as follows.

(1) Physical Parameters

24 sub-basins and 56 precipitation gauging stations which were the same as those of MOC(1987) were selected(Fig. 2). Fig. 3 shows the configuration of the Nakdong River basin used with SSARR model. Area and area ratio of elevation bands are calculated to use in IS watershed model which divides a sub-basin into lots of bands. Reservoir characteristic data is series of discharge history of Andong, Imha, Hapcheon, Namgang Dam which have regulation gates for operation.

(2) Hydrometeorologic Parameters

We selected '93 year as a normal period and '94 year as a dry period, and the missing data were generated through RDS(Reciprocal Distance Squared) method. Mean areal rainfall data calculated by Thiessen method were calibrated by considering area ratio and rainfall weighting of elevation bands. Parameters for interception and evapotranspiration with regard to latitude, month, elevation, rainfall intensity, snow pack are determined by referring to SSARR manual(1991). Mean annual temperature data were used for evapotranspiration calibration.

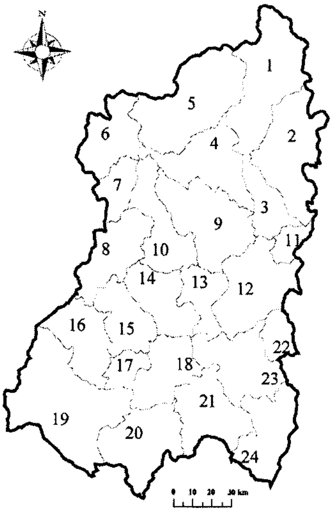

Fig. 2. Division Map for Sub-basin of Nakdong River Watershed

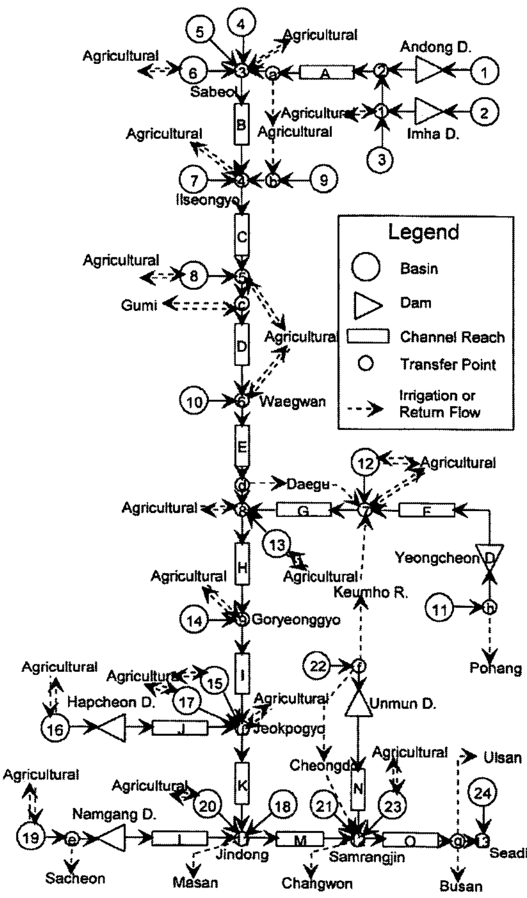

Fig. 3. Configuration of the Nakdong River Basin Used with the SSARR Model

The main advantage of the IS watershed model is the capability of the simulation of snow. To simulate the snowfall runoff, snowpack data such as snowfall, depth of snowfall, and elevation line of snowfall are required. Data such as snow melt and ice formation by ground temperature and rainfall are also required, but this type of data are hard to find in Nakdong River basin. Annual snowfall is approximately 2.3% of annual rainfall in Nakdong River basin, and is considered to be such a small quantity as only amounts to 28% of rainfall data of January. We didn't include simulation of snowfall because lots of snowfall are evaporated and they are thought to be negligible in the runoff mechanism.

(3) Process Parameters

SMI-ROP, one of the most sensitive parameter, was initially set by KOWACO(1989) values. SMI-ROP table was divided into 3 medium-sized basin according to CN value. CN value from 1 to 9 sub-basin was assigned 62, from 10 to 18 sub-basin 63, and from 19 to 24 sub-basin 64, which were modified through the model calibration. The BII versus base flow percentage (BFP) table and surface flow versus subsurface flow table were also referred to KOWACO(1989), and they were applied to 3 regions as in SMI.

Reference values of other parameters concerning BII such as BIITS, BIIMX, BFLIM and lower zone such as PBLZ, DGWLIM were referenced to SSARR Manual(1991).

Parameters for watershed routing are the number of imaginary reservoirs and time of storage, and the reference values were determined by considering watershed area, channel length, and time of concentration. In channel routing, parameters to be calibrated are the number of imaginary reservoirs and time of storage as in watershed routing where continuous imaginary reservoir routing method is used. But it is different with watershed modeling in that storage time of imaginary reservoirs, T_s, is determined by Eq. (5). General procedure for determination of the number of imaginary reservoirs, values of KTS, n are as follows.

1) Suppose n. Generally 0.20 is preferred.

2) Determine total time of storage. This is approximately the same as the time of concentration(If the channel is linear, they are the same).

3) Determine the number of imaginary reservoirs. Generally make one reservoir for each 8-16 km. We can calculate the time of storage for each imaginary reservoir.

4) Calculate KTS using Eq. (5).

Because of the limitation of verification data, the time of concentration for each channel in the applied basin was calculated using Eq. (6) which had been developed by USBR.

$$T_c = (0.871\frac{L^3}{H})^{0.385} \tag{6}$$

where T_c is the time of concentration(hr), L is the channel length(km), and H is the elevation difference(m). The calculated parameters for channel routing such as time of concentration, time of storage, and KTS are listed in Table 1, where manning n is fixed to 0.20.

Table 1. Parameters for Channel Routing

Channel Name	Channel Reach	Length (km)	Elev. Diff. (m)	Time of Concentration (hr)	Number of Reservoirs	Time of Storage (hr)	Discharge (m^3/sec)	*KTS*
A	Andonggyo~Sabeol	64.5	38.0	28.8	5	5.75	20	10.47
B	Sabeol~Nakdong	25.4	6.8	19.0	2	9.50	20	17.30
C	Nakdong~Sunsan	35.7	8.7	25.6	3	8.54	20	15.55
D	Sunsan~Waegwan	30.9	5.8	25.3	3	8.45	20	15.38
E	Waegwan~Sungseo	16.7	3.5	15.1	2	7.56	30	14.93
F	Yeongcheon Dam~Dongchon	56.6	93.5	17.5	4	4.37	20	7.96
G	Dongchon~Sungseo	28.0	13.7	16.2	2	8.12	20	14.78
H	Sungseo~Goryeonggyo	25.0	5.3	16.6	2	8.30	40	17.36
I	Goryeonggyo~Jeokpogyo	40.2	7.4	31.3	3	10.42	50	22.79
J	Hapcheon~Jeokpogyo	48.7	76.1	15.9	4	3.98	20	7.25
K	Jeokpogyo~Jindong	30.4	2.6	33.9	3	11.29	60	25.60
L	Namgang Dam~Jindong	81.1	20.2	47.8	6	7.96	20	14.49
M	Jindong~Samrangjin	38.8	4.1	37.7	3	12.56	70	29.38
N	Unmun Dam~Samrangjin	60.5	107.2	17.9	5	3.58	20	6.52
O	Samrangjin~Seadike	47.5	4.8	44.8	4	11.20	80	26.91

3.2 Water Budget Data

To enhance the accuracy of the watershed model, it is required that water budget analysis for the basin include agricultural, domestic, and industrial water diversion between sub-basins and outside the basin. Most agricultural water and water supply system, such as Gumi which took water from the main channel and Chungdo from Unmun Dam, are the cases where water is returned to their own basin. There are some cases for diversion to the exterior of the Nakdong River basin.

Agricultural water taken from Poongyang and Yangseo intake stations is diverted to the Wicheon basin which is short of water during irrigation period, from May to September. It is the case of inter-basin water diversion where agricultural water is moved to other sub-basin and discharged to a different channel. Inter-basin water diversion also happens in the case when the water taken from the downstream of Waegwan and Unmun Dam is supplied to Daegu area. Water diversions to the exterior of Nakdong River basin are the such cases as the water taken from Yeongcheon Dam to Pohang in Hyungsan basin to supply the industrial water, the water drained to Sacheon at Namgang Dam during flood period, and the water from Jindong, Bonpo, Wondon, and Mulgeum intake stations to Masan, Changwon, Ulsan, and Busan area to supply the domestic and industrial water respectively. The water diversion systems over 1.0 CMS are shown in Fig. 3, and the water volumes for each intake station were examined. But the usage of agricultural water has not been examined, so it should be estimated indirectly by calculating required water for a agricultural land area and cultivating crops. Yearly water demand for agriculture is found to be lowered by 0.6% from the regression analysis of previous agricultural water data. Agricultural water of sub-basin and channels for '93 and '94 was estimated to be lowered by 3.0% and 3.6% compared with the year '88(KOWACO, 1989). The water taken from a basin and a channel might either be drained to the same basin and channel or not. This return rate is very important for water budget analysis. Since it is hard to find concurrent data of channel flow and intake water to calculate this return flow in this river basin, return flow is determined by constant return rates of intake water. Return flow rates have different values for every water usage and season. Low flow management system for Nakdong River basin uses 80% and 60% as a return rate and drainage rate for domestic and industrial water, and 30-40% (March-August) and 60-80% (August-November) for agricultural water.

This model can simulate agricultural, domestic, and industrial water by representing intake water as minus flow to the imaginary basin. It can simulate return flow through the storage effect for agricultural land by considering imaginary channel with long time of storage.

4. Model Calibration

Although parameter calibration should be accomplished by using computed and observed discharges of each sub-basin, it is hard to find observation data and reliable rating curves except for some control points in the research area. Therefore, the parameter calibration is done at 7 control points, such as Sabeol, Ilsungyo, Waegwan, Goryeonggyo, Jeokpogyo, Jindong, and Samrangjin, which are presented in Fig. 3.

4.1 Sensitivity Analysis

Sensitivity analysis of the process parameters among the three kind of parameters stated in section 3.1 was done for one selected sub-basin. Reference values of sensitivity analysis were determined in section 3.1, and they are shown in Table 2. Sensitivity analysis was performed for sub-basin 8 which is located at upstream and its area is close to the average value of all sub-basins. For the analysis we selected hydrometeorological data which is composed of 30 days before and after maximum discharge in 1993 and 1994 where severe drought was sustained.

Table 2. Reference Values for Sensitivity Analysis of Process Parameters

<table>
<tr><td rowspan="2">SMI</td><td>SMI (cm)</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>999</td></tr>
<tr><td>ROP (%)</td><td>7</td><td>17</td><td>39</td><td>62</td><td>79</td><td>87</td><td>100</td><td>100</td></tr>
<tr><td rowspan="3">BII</td><td>BII (cm/day)</td><td>0.0</td><td>1.0</td><td>1.5</td><td>2.0</td><td>2.5</td><td>3.0</td><td>5.0</td><td>100.0</td></tr>
<tr><td>BFP (%)</td><td>43</td><td>15</td><td>13</td><td>12</td><td>11</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td colspan="9">BIITS : 40 hr, BIIMX : 3cm/day, BFLIM : 0.13cm/hr</td></tr>
<tr><td rowspan="2">S-SS</td><td>input rate (cm/hr)</td><td>0.0</td><td>0.5</td><td>1.0</td><td>1.5</td><td>2.0</td><td>2.5</td><td colspan="2">3.0</td></tr>
<tr><td>sf. comp. (cm/hr)</td><td>0.00</td><td>0.25</td><td>0.75</td><td>1.25</td><td>1.75</td><td>2.25</td><td colspan="2">2.75</td></tr>
<tr><td>PBLZ</td><td colspan="9">50 %</td></tr>
<tr><td>T_s (hr)</td><td colspan="9">surface:3, subsurface:10, baseflow:100, lower zone:1,000</td></tr>
</table>

The appropriate range of each parameter for sensitivity analysis is determined referring to SSARR Manual(USACE, 1991). Sensitivity analysis for SMI-ROP curve is obtained using the increased or decreased value by 10% from the reference value. Sensitivity analysis for BII-BFP curve is done for increased or decreased value by 10% with BII being equal to 0. S-SS curve is also done from increased or decreased value by 0.15cm/hr. Reference values, ranges and sensitivities of various parameters related to watershed runoff are shown in Table 3 for highflow, and in Table 4 for lowflow respectively. We chose the peak discharge for highflow and discharge at the end time of direct runoff(just after inflection point: 20th day in 1993, and 13th day in 1994) as reference discharges of sensitivity. Sensitivity is defined as geometric mean of discharge variation for a increase or decrease of parameters[Eq. (7)].

$$\sqrt{\frac{[\frac{(Q_u - Q_o)/Q_o}{(P_u - P_o)/P_o}]^2 + [\frac{(Q_o - Q_l)/Q_o}{(P_o - P_l)/P_o}]^2}{2}} \quad (7)$$

where Q and P indicate discharges and the values of parameters respectively, and subscripts o, u, l represent reference values, upper and lower limit respectively. As shown in Tables 3 and 4, it is identified that SMI is the most sensitive variable for high and lowflow region. Storage time of surface and subsurface water are sensitive in highflow region, and BII, PBLZ which is the portion of return flow from groundwater to groundwater and storage time of groundwater are sensitive parameters for lowflow region.

Watershed routing parameters, related to 4 types of flow fields which are surface water, subsurface water, groundwater, and return flow from groundwater, include the number of imaginary reservoirs and storage time for each flow field. These parameters should be computed according to watershed area, mean surface runoff length, slope, lag time, land usage, and soil type. Generally they are determined by sensitivity analysis and trial and error method. In general, as storage time is getting shorter, peak discharge gets larger and its occurrence time gets shorter. For surface water we examined the behavior of runoff hydrograph by changing the storage time from 2 hours to 4 hours by 1 hour interval. Peak discharge increased by the amounts of 32m^3/sec at 2 hour storage time compared with 3 hour's in 1993 year data, and there is no significant variation in 1994 year data. As a result, sensitivity does not have quite large value for both high and lowflow. We can consider the storage time as a function of discharge instead of a constant value, which is closer to real phenomena that storage time gets shorter as discharge increases. When the storage time of surface water is a function of discharge, peak discharge increases more than 100m^3/sec in year 1993 data. This shows quite increased value compared to the constant storage time, 2 hours. This result can be explained by the concentration effect of discharge just before peak time when storage time is a function of discharge. The result of 1994 year shows that peak discharge makes little difference between the case of storage time as a function of discharge and the case of a constant storage time such as 3 hours. The reason is that the discharge of 1994 is less than 100m^3/sec making no significant difference in storage time.

Table 3. Sensitivity Analysis of Parameters Related to Watershed Discharge for Highflow

Parameter	Range	Peak Discharge(m^3/sec)		Sensitivity	
		'93 Data	'94 Data	'93 Data	'94 Data
SMI	SMI1	446.0	75.6	0.48	0.37
	SMI2	502.9	81.4		
	SMI3	541.4	87.5		
BII	BII1	520.3	84.2	0.08	0.10
	BII2	502.9	81.4		
	BII3	495.5	78.7		
S-SS	S-SS1	539.5	81.3	0.06	0.00
	S-SS2	502.9	81.4		
	S-SS3	516.8	81.5		
BIITS	30 hr	506.7	82.8	0.03	0.06
	40 hr	502.9	81.4		
	50 hr	499.5	80.3		
BIIMX	1 cm/day	485.3	81.4	0.04	0.00
	3 cm/day	502.9	81.4		
	5 cm/day	502.9	81.4		
BFLIM	0.08 cm/day	503.2	81.4	0.00	0.00
	0.13 cm/day	502.9	81.4		
	0.18 cm/day	502.9	81.4		
PBLZ	25 %	507.5	83.7	0.02	0.06
	50 %	502.9	81.4		
	75 %	498.4	79.2		
T_s (surface)	2 hr	535.2	81.1	0.14	0.01
	3 hr	502.9	81.4		
	4 hr	513.9	81.3		
T_s (subsurface)	8 hr	523.7	81.8	0.15	0.02
	10 hr	502.9	81.4		
	12 hr	504.5	81.0		
T_s (baseflow)	50 hr	517.5	86.0	0.04	0.09
	100 hr	502.9	81.4		
	150 hr	498.8	79.3		
T_s (lower zone)	500 hr	503.2	81.2	0.00	0.02
	1,000 hr	502.9	81.4		
	1,500 hr	503.5	82.3		

For subsurface flow, simulation was done for two cases: one is the case of a change of storage time from 8 hours to 12 hours by 2 hour interval and the other is the case of a storage time as a function of discharge. The results are similar to those of surface water for high and lowflow. For groundwater and return flow from groundwater, we considered constant time of storage only. It doesn't have a significant effect for peak flow, but it is very sensitive to

Table 4. Sensitivity Analysis of Parameters Related to Watershed Discharge for Lowflow

Parameter	Range	Low Discharge(m^3/sec)		Sensitivity	
		'93 Data	'94 Data	'93 Data	'94 Data
SMI	SMI1	19.3	7.5	0.42	0.43
	SMI2	21.8	8.4		
	SMI3	22.5	8.9		
BII	BII1	19.5	7.0	0.31	0.52
	BII2	21.8	8.4		
	BII3	24.0	9.9		
S-SS	S-SS1	21.1	8.6	0.03	0.02
	S-SS2	21.8	8.4		
	S-SS3	22.2	8.4		
BIITS	30 hr	22.0	8.3	0.03	0.08
	40 hr	21.8	8.4		
	50 hr	21.7	8.6		
BIIMX	1 cm/day	24.8	8.4	0.15	0.00
	3 cm/day	21.8	8.4		
	5 cm/day	21.3	8.4		
BFLIM	0.08 cm/day	21.7	8.4	0.01	0.00
	0.13 cm/day	21.8	8.4		
	0.18 cm/day	21.8	8.4		
PBLZ	25 %	27.3	10.9	0.51	0.58
	50 %	21.8	8.4		
	75 %	16.2	6.0		
T_s (surface)	2 hr	21.0	8.3	0.11	0.08
	3 hr	21.8	8.4		
	4 hr	22.6	8.7		
T_s (subsurface)	8 hr	21.2	8.4	0.13	0.00
	10 hr	21.8	8.4		
	12 hr	22.3	8.4		
T_s (baseflow)	50 hr	16.4	8.7	0.36	0.27
	100 hr	21.8	8.4		
	150 hr	20.6	6.8		
T_s (lower zone)	500 hr	23.4	8.4	0.10	0.15
	1,000 hr	21.8	8.4		
	1,500 hr	21.9	9.3		

subsurface flow and slightly sensitive to return flow from groundwater in lowflow region(Table 4). Parameters for channel routing such as n, the number of imaginary reservoirs, and KTS have been shown in Table 1 whose reference value, n, is 0.2. Sensitivity analysis was done for n and KTS with keeping the number of imaginary reservoirs constant as in watershed routing. Table 5 shows the result of sensitivity analysis where the conditions are the same

Table 5. Sensitivity Analysis of Parameter, *n* for Channel Routing

Control Point	Observed Peak Discharge (m^3/sec)	Calculated Peak Discharge (m^3/sec)					
		$n = 0.0$	$n = 0.1$	$n = 0.2$	$n = 0.3$	$n = 0.4$	$n = 0.5$
Sabeol	2,196	2,622	2,511	2,643	2,689	2,694	2,694
Ilseongyo	3,387	2,811	2,716	2,834	2,862	2,864	2,864
Waegwan	3,715	3,006	2,839	2,993	3,057	3,072	3,081
Goryeonggyo	5,879	3,415	3,232	3,392	3,461	3,475	3,483
Jeokpogyo	5,611	3,776	3,527	3,750	3,821	3,832	3,837
Jindong	7,763	4,369	3,987	4,370	4,417	4,422	4,424
Samrangjin	7,570	4,926	4,139	4,765	4,972	4,991	4,993

Table 6. Sensitivity Analysis of Parameter, *KTS* for Channel Routing

Control Point	Observed Peak Discharge (m^3/sec)	Calculated Peak Discharge (m^3/sec)				
		$KTS \times 0.1$	$KTS \times 0.5$	$KTS \times 1.0$	$KTS \times 1.5$	$KTS \times 2.0$
Sabeol	2,196	2,694	2,694	2,689	2,513	2,039
Ilseongyo	3,387	2,864	2,864	2,862	2,749	2,212
Waegwan	3,715	3,088	3,088	3,057	2,902	2,178
Goryeonggyo	5,879	3,490	3,490	3,461	3,311	2,446
Jeokpogyo	5,611	3,842	3,842	3,821	3,654	2,649
Jindong	7,763	4,422	4,424	4,417	4,300	2,865
Samrangjin	7,570	4,987	4,989	4,972	4,648	3,397

with that of Table 1. If the value of n changes, KTS value changes accordingly in order to keep the time of storage in table 1 constant. n value has range of -1.0 ~1.0. When n is minus, peak flow of Eq. (5) has a low value with increasing time of storage by the increase of discharge. This reasoning is contrary to observed peak flow in Table 5.

To increase the peak discharge at the downstream, n should have a larger value. But the augmentation rate of peak flow with increased n was very small except for the that n is zero when time of storage is not a function of discharge. Peak discharges are shown in Table 6 where 10%, 50%, 90%, 150%, and 200% of the reference value of KTS were selected with fixed n, 0.2. The peak discharge is greatly lowered with increased KTS, but the augmentation of peak discharge is smaller than 1% with decreased KTS.

4.2 Determination of Parameters

It is required to determine objective function for parameter estimation. Generally, objective function has the form of minimizing the errors between observed data and calculated values, which are divided into absolute and relative errors. But the absolute error tends to minimize the error of highflow region and might decrease the accuracy of lowflow region. The relative error tends to focus on the lowflow region and neglects the highflow region. Therefore, the objective function was selected respectively in two regions, because parameter estimation processes were divided into two regions according to the sensitivity to discharge. The objective function for highflow at 6 control points except for Samrangjin is minimizing the relative error of maximum annual flow, whose related parameters are SMI and time of storage. In a lowflow region, the objective function at the same control points is minimizing mean absolute error of flow under a specified high discharge, whose related parameters are BII, PBLZ, and storage time of groundwater. But daily runoff model has the limitation in calibrating the highflow region, which has large fluctuations in a small time scale. Parameter calibration for lowflow region also has limit due to the shortage of observation data for an individual sub-basin. Exact parameter calibration process needs long-term sub-basin runoff data, and trial and error method was used for parameter estimation of 6 control points. Parameter estimation strategy explained previously and results of sensitivity analysis were useful for the estimation.

From the results of sensitivity analysis for '93 and '94 data, parameters other than processor parameters, such as SMI, Ts, BIIP, and BLZ are very sensitive in high or lowflow region, can be fixed to the reference values. Table 7 and 8 shows the parameter estimation results for SMI and Ts done by trial and error method, which have major contribution to peak discharge and were represented as a function of discharges.

In Table 7, SMI-A is for sub-basins from 1 to 10 which are upper reach of Waegwan, and SMI-B is for sub-basins from 11 to 24. TS and TSS in Table 8 were applicable to all region which were parameters for surface flow and subsurface flow respectively. Parameters such as BII, PBLZ, storage time Ts of groundwater and return flow from groundwater in lowflow region were determined by trial and error method considering the estimation results of highflow region. PBLZ has the same value, and the estimation results are shown in Fig. 9. The value of Ts for groundwater flow and return flow from groundwater are 150 hr and 1,500 hr respectively. Fig. 4 shows the simulation results for Jindong('93) using estimated parameters. Tables 10, 11 shows relative errors before and after calibration in highflow region, and Table 12 shows relative errors for lowflow region. It is thought that the error for highflow region decreases than before. In lowflow region, the calibration result is good for '94 year data, but the data for downstream of Goryeonggyo have poorer results than before calibration.

Table 7. SMI-ROP Table

SMI (cm)	ROP(%)	
	SMI-A	SMI-B
0	10	10
1	15	25
2	25	35
3	45	55
4	65	75
5	75	85
6	80	90
10	100	100
999	100	100

Table 8. T_s Values for Discharge

Discharge (m^3/sec)	T_s (hr)	
	TS	TSS
0	10	13
10	8	11
15	7	10
20	6	9
40	5	8
100	4	7
400	3	6
1000	2	5

Table 9. BII-BFP Table

BII (cm/day)	BFP(%)		
	BII-a	BII-b	BII-c
0.0	40	41	39
1.0	15	16	14
1.5	13	14	12
2.0	12	12	11
2.5	11	11	10
3.0	10	10	10
5.0	10	10	10
100.0	10	10	10

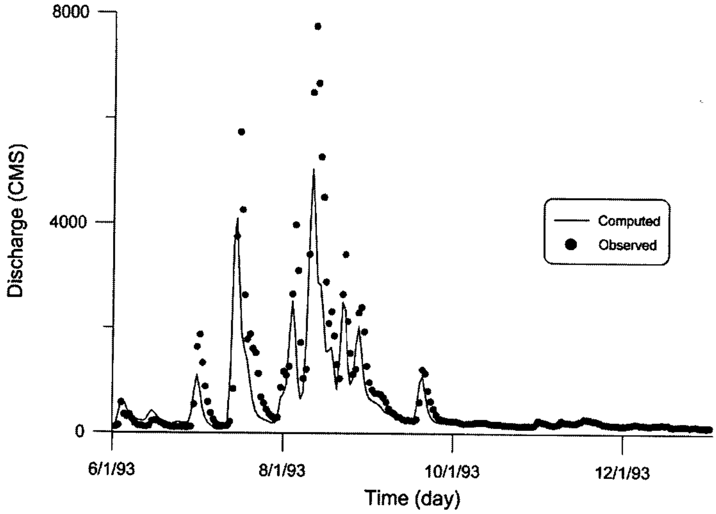

Fig. 4. Result for '93 Data at Jindong with the SSARR Model(after Calibration)

Table 10. Errors for Highflow Region(Before Calibration)

Control Point	1993			1994		
	Observed Discharge (CMS)	Calculated Discharge (CMS)	Relative Error (%)	Observed Discharge (CMS)	Calculated Discharge (CMS)	Relative Error (%)
Sabeol	2,196	1,806	17.8	1,394	1,403	0.6
Ilseongyo	3,387	2,228	34.2	1,241	1,493	20.3
Waegwan	3,715	2,434	34.5	940	1,374	46.2
Goryeonggyo	5,879	2,891	50.8	1,648	1,248	24.3
Jeokpogyo	5,611	3,121	44.4	1,307	1,191	8.9
Jindong	7,763	3,799	51.1	1,418	1,119	21.1
Average			38.8			20.2

Table 11. Errors for Lowflow Region(After Calibration)

Control Point	1993			1994		
	Observed Discharge (CMS)	Calculated Discharge (CMS)	Relative Error (%)	Observed Discharge (CMS)	Calculated Discharge (CMS)	Relative Error (%)
Sabeol	2,196	2,400	9.3	1,394	1,509	8.2
Ilseongyo	3,387	2,872	15.2	1,241	1,546	24.6
Waegwan	3,715	3,252	12.5	940	1,537	63.5
Goryeonggyo	5,879	4,032	31.4	1,648	1,444	12.4
Jeokpogyo	5,611	4,438	20.9	1,307	1,291	1.2
Jindong	7,763	5,051	34.9	1,418	1,333	6.0
Average			20.7			19.3

Table 12. Errors for Lowflow Region(Unit : CMS)

Control Point	Before Calibration		After Calibration	
	1993	1994	1993	1994
Sabeol	23.3	28.0	23.8	24.7
Ilseongyo	33.4	15.5	33.5	13.7
Waegwan	36.9	46.4	27.1	43.5
Goryeonggyo	50.0	32.9	57.0	35.6
Jeokpogyo	54.8	30.2	56.2	22.4
Jindong	40.8	48.9	51.6	44.9
Average	39.9	33.7	41.5	30.8

5. Model Verification and Yearly Water Budget Analysis

5.1 Model Verification

For model verification, flow analysis was done using the parameters determined by the model calibration. The year of '92 as lowflow period was selected for model verification, and the results at the Jindong point are shown in Fig. 5. Relative errors in highflow region and absolute errors in lowflow region for 7 control points are shown in Table 13. By the verification results of highflow, we can see the mean of relative errors for the verification results is larger than errors for the calibration. It might be thought to be so due to the observation error at Ilseongyo point, whose observation value is larger than the others, making the verification process as a meaningful result.

The absolute error for lowflow period in verification is similar to the error for calibration, and the process is considered to be good enough. Even though this result is not prominent compared with tank model used currently, it is expected to produce superior results in that

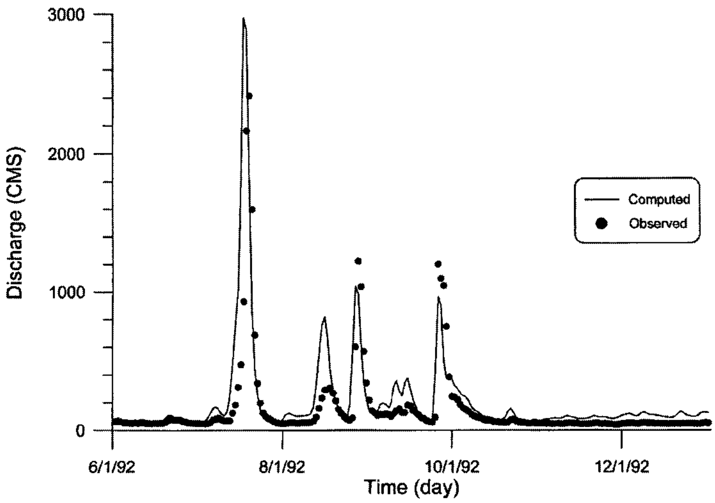

Fig. 5. Result for '92 Data at Jindong with the SSARR Model(after Verification)

Table 13. The Verification Result of the Model

Control Point	Error for Highflow			Error for Lowflow (CMS)
	Observed Discharge (CMS)	Calculated Discharge (CMS)	Relative Error (%)	
Sabeol	808	717	11.3	27.4
Ilseongyo	2,545	1,196	53.0	45.0
Waegwan	1,788	1,745	2.4	18.1
Goryeonggyo	2,160	2,416	11.9	38.2
Jeokpogyo	2,094	2,713	29.6	36.4
Jindong	2,415	2,972	23.1	58.1
Average			21.9	37.2

this model suggests objective and precise methods for determination of parameter calibration.

5.2 Yearly Water Budget Analysis

SSARR model which has been used previously was DC(depletion curve) watershed model. In this research, we used IS(integrated snowband) watershed model which is the latest version of SSARR model('91). IS watershed model includes all functions of DC model, and it also enhanced long term runoff analysis, interception, long term return flow from groundwater, and evapotranspiration. This program is designed to support both batch(BA) mode and interactive (IA) mode which is required to setup lowflow management system. Recent version of SSARR model is capable of presenting the result of monthly water budget analysis as a tabular form listing rainfall, interception, evapotranspiration, and runoff data. Table 14 shows the water budget results of year '93 data in volume(m^3) which are calculated by multiplying the basin area by the analysis data(cm). In '93, the total rainfall is 1316.8mm which is more than the annual mean rainfall, 1167.0mm. The loss by interception and evapotranspiration is 50.3%, and direct runoff is about 39.6% and base flow is 13.0%. Fig. 6 shows mean annual water balance of 1993 where the sum of loss and total runoff exceeds total rainfall, and it means that the long range of storage time of lower zone of previous year has affected this year. Total

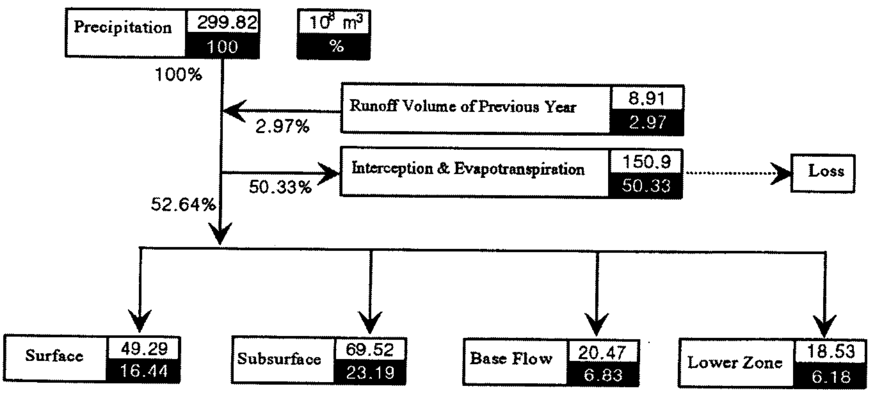

Fig. 6. Mean Annual Water Balance(1993)

Table 14. Yearly Water Budget Analysis('93)

Basin No.	Watershed Area (km^2)	Rainfall ($10^8 m^3$)	Interception ($10^8 m^3$)	Evapo-transpiration ($10^8 m^3$)	Runoff Volume ($10^8 m^3$)				
					Surface	Subsurface	Base Flow	Lower Zone	Total Runoff
1	1583.5	19.84	3.90	7.45	3.46	3.30	1.35	1.12	9.24
2	1360.5	16.97	3.35	6.06	3.16	2.94	1.07	0.91	8.08
3	604.3	8.05	1.30	2.59	1.60	1.59	0.53	0.47	4.18
4	1038.5	14.82	2.22	4.62	3.18	3.05	1.00	0.73	7.96
5	1806.7	24.48	4.12	8.16	5.49	5.03	1.64	1.42	13.58
6	911.4	14.27	2.06	4.60	3.11	3.00	1.03	0.98	8.11
7	419.7	6.50	0.90	2.08	1.34	1.33	0.46	0.42	3.55
8	1000.1	13.00	2.42	4.25	2.58	2.45	0.79	0.71	6.52
9	1408.7	17.24	3.04	6.09	3.17	3.05	1.11	0.95	8.29
10	941.0	11.89	2.24	3.75	1.70	2.76	0.82	0.71	5.99
11	234.6	3.03	0.49	0.93	0.46	0.76	0.21	0.20	1.63
12	1309.3	15.43	2.92	4.97	2.15	3.52	1.07	0.95	7.68
13	544.0	6.59	1.20	2.14	0.89	1.47	0.48	0.43	3.26
14	767.6	10.05	1.71	3.14	1.48	2.41	0.72	0.63	5.25
15	781.1	10.88	1.80	3.13	1.71	2.83	0.77	0.68	6.00
16	924.6	13.08	2.29	3.90	2.10	3.46	0.91	0.80	7.27
17	401.0	6.07	0.95	1.73	0.94	1.55	0.46	0.41	3.36
18	808.3	10.43	1.86	3.18	1.54	2.55	0.76	0.69	5.53
19	2285.0	11.90	5.42	4.74	0.44	1.04	0.46	0.90	2.84
20	1181.3	17.72	2.84	4.80	2.49	6.05	1.33	1.23	11.10
21	976.4	14.59	2.31	4.13	2.03	5.07	1.10	1.00	9.19
22	301.5	3.27	0.69	1.09	0.31	0.74	0.21	0.19	1.45
23	1145.8	15.83	2.74	4.59	2.04	4.96	1.15	1.03	9.18
24	921.3	13.86	2.18	3.85	1.91	4.60	1.06	0.98	8.56
Total	23656.2	299.82	54.94	95.96	49.29	69.52	20.47	18.53	157.82
%		100.00	18.32	32.01	16.44	23.19	6.83	6.18	52.64

runoff rate, 52.6% means the summation of runoff from all sub-basins, and it is different from total catchment yield of Nakdong River basin which is calculated at the Nakdong sea dike. But total sub-basin runoff is useful for the calculation of catchment yield which needs all the values such as reservoir discharges, agricultural and industrial water use, et. al. This value is lesser than the value of 54.6%(Lee, 1989), but greater than 49%(KICT, 1990) and 42%(KICT, 1993).

6. Conclusions

We used IS watershed model instead of DC watershed model for Nakdong River basin, and the conclusions are as follows:

(1) It is important for daily lowflow runoff simulation to determine evapotranspiration and interception. IS watershed model is capable of determining these values with confidence, and analysis of long-term return flow from groundwater can improve the accuracy of lowflow analysis.

(2) SMI is sensitive in both high and lowflow region, and storage time of surface and subsurface flow is especially sensitive in highflow region when this value is a function of

flowrate rather than fixed to a constant value. In lowflow region, SMI, BII, PBLZ, and storage time of groundwater are considered to be sensitive parameters.

(3) Trial and error method was used for optimal parameter estimation whose objective function was minimizing the errors at 7 control points.

(4) According to the annual water budget analysis of SSARR model, 50.3% of total rainfall was intercepted or evapotranspirated. Total runoff is 52.6% of which direct runoff is 39.6% and base flow is 13.0%.

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